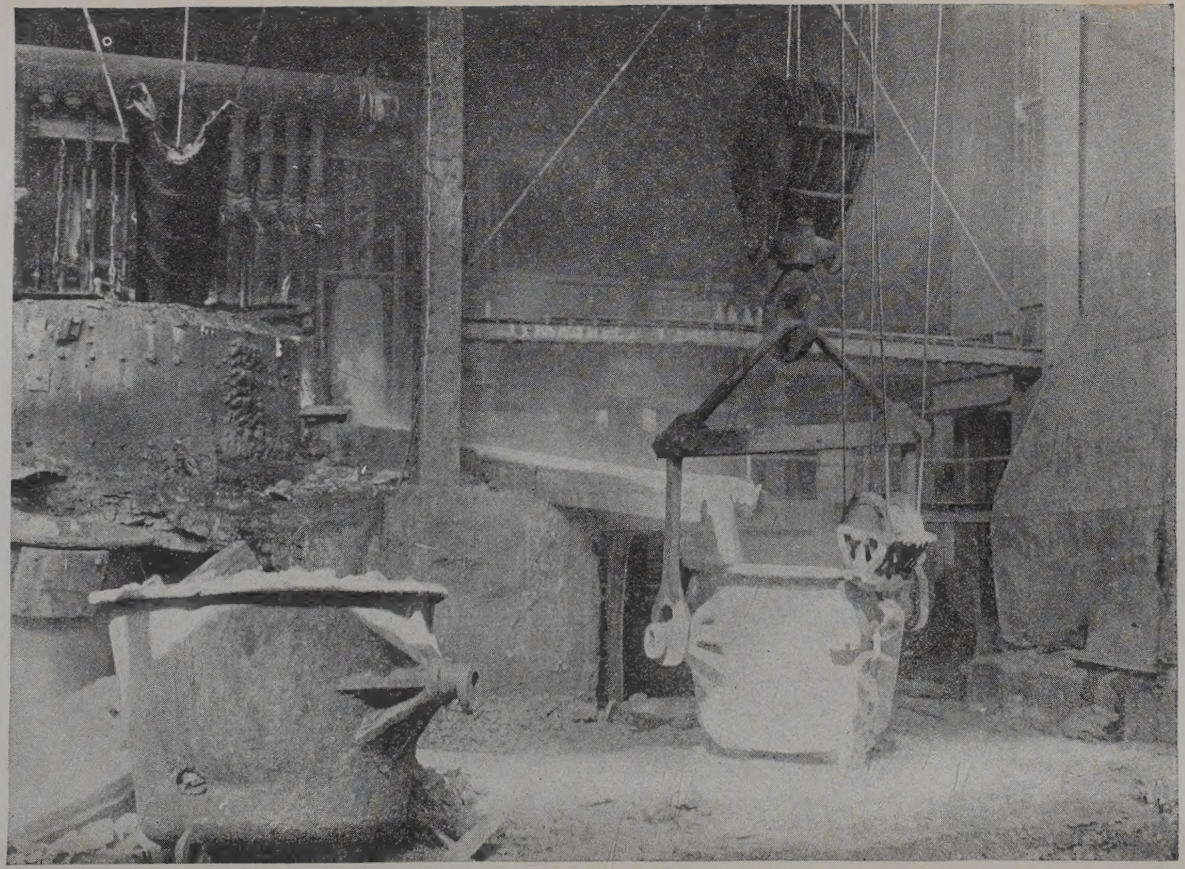

MATTE LADLES AT WORK TRANSFERRING MATTE FROM THE SETTLERS TO THE CONVERTERS

Courtesy of United States Metal Refining Company, New York City

Modern Shop Practice

A General Reference Work on

Machine Shop Practice and Management, Production Manufacturing, Metallurgy, Welding, Tool Making, Tool Design, Die Making and Metal Stamping, Foundry Work, Forging, Pattern Making, Mechanical and Machine Drawing, Etc.

Editor-in-Chief

HOWARD MONROE RAYMOND, B.S.
President, Armour Institute of Technology

Assisted by a Corps of

MECHANICAL ENGINEERS, DESIGNERS, AND SPECIALISTS IN SHOP METHODS AND MANAGEMENT

Illustrated with over Two Thousand Engravings

SIX VOLUMES

AMERICAN TECHNICAL SOCIETY
CHICAGO U.S.A.

1928

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THE editors have freely consulted the standard technical literature of America and Europe in the preparation of these volumes. They desire to express their indebtedness, particularly, to the following eminent authorities, whose well-known treatises should be in the library of everyone interested in Modern Shop Practice.

Grateful acknowledgment is also expressed for the invaluable cooperation of the foremost manufacturers and engineering firms in making these volumes thoroughly representative of the best and latest practice in machine and pattern shops, foundries, and drafting rooms, and in the construction and operation of machine tools, and other classes of modern machinery; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

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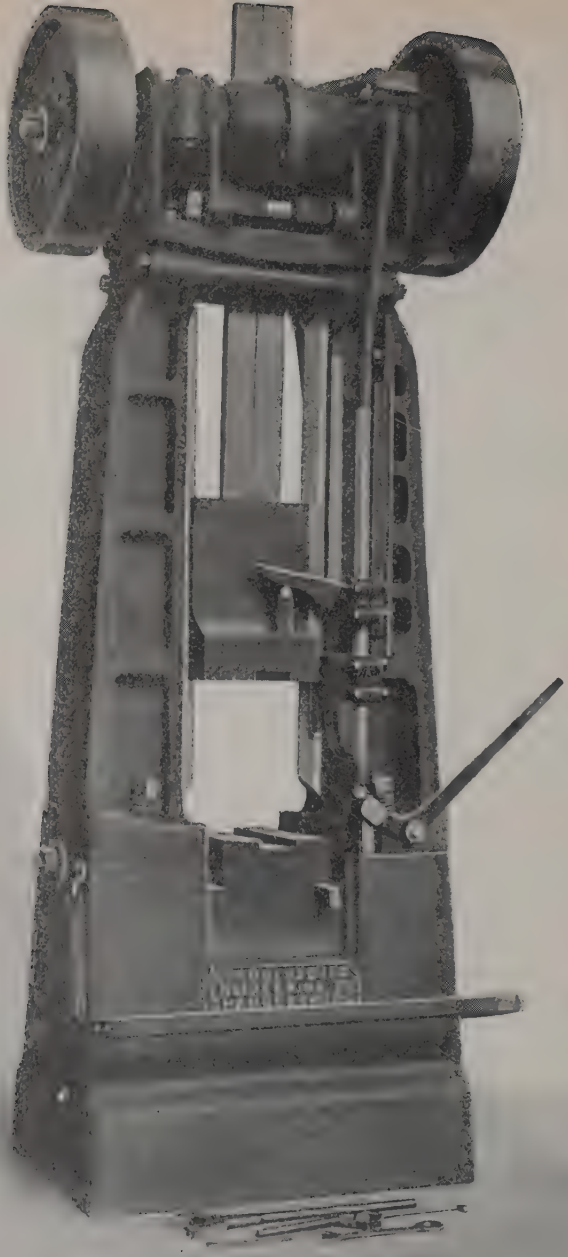

CHAMBERSBURG BOARD DROP HAMMER

Courtesy of Chambersburg Engineering Company, Chambersburg, Pennsylvania

Foreword

A LITTLE more than a century ago the first prime movers were invented and developed, and mechanical development had its beginning. With the development of machines came the development of mechanics to run these machines, to fabricate the parts and to assemble them into the finished articles. The evolution of both machines and mechanics has been marvelous, the accuracy of workmanship today being easily two hundred times that of a century ago, and the speed of manufacture probably much more than this. Since that time one industry has helped to develop others until today the mines produce ore in large quantities to supply the iron, copper, and other metals; the great steel mills supply the raw or fabricated material; the foundries and forging shops fashion the many castings and forgings for the intricate machines to be built; the immense shops machine the parts and assemble them for the market. Everywhere we turn we find a manufactured article which has gone through these various changes from raw material to finished product.

¶ "Production" methods have enormously increased the output of our shops and the machines which have made this development possible are of a diversified character—speed lathes, planers, multiple drillers, grinders, milling machines, stamping machines, die presses and the jigs, tools and dies which go with them—all of these have contributed to the accuracy and speed of manufacture. The demands of the automobile industry have done wonders in hastening this development as the manufacture of the parts in duplicate was absolutely necessary in order to cheapen the price of the

assembled machines. The fact that many of the present-day automobiles are shipped "knocked down" to assembly plants without ever having been put together is an eloquent testimonial to the accuracy with which the duplicate parts are built. Another contributing factor in modern production methods is the development of high speed steels which enable the operators to run the machines at speeds hitherto unattainable.

¶ And yet with all this wonderful development of the machines themselves and the design of what are termed "automatics," the workman has not lost his skill. In fact, one trip to a well-organized scientific machine shop will teach any skeptic that the intelligent workman who has contributed so largely to the mechanical developments of the past twenty years is more skilled, more intelligent, certainly better paid, and more interested in his work than ever.

¶ But this same skilled mechanic is today a specialist. He has no opportunity to build a complete machine or even a small part of one; his active work is carried on along rather narrow lines. Consequently, it is all the more necessary for him to have a standard reference work to help him in other shop lines with which he is unfamiliar. "Modern Shop Practice" is such a work—one which has been tested through six editions—and the practical treatises on the various shop subjects have been supplied by well-known teachers and practical men and are strictly up to date. The authors have at all times kept in mind the practical nature of their subjects and numerous shop kinks and other helpful suggestions have been introduced. It is the hope of the publishers that this new edition will supply the needs of both the skilled mechanic and the layman who is interested in mechanical affairs.

¶ In conclusion, grateful acknowledgment is given to the authors and collaborators—engineers and designers of wide practical experience and teachers of recognized ability—without whose cooperation this work would have been impossible.

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TABOR MOLDING MACHINE WITH PATTERNS AND MOLD IN POSITION

The view also shows numerous "chills" in position in the mold and a completed casting in the background

FOUNDRY WORK

PART I

MOLDING PRACTICE

Introductory. *Foundry work* is the name applied to that branch of engineering which deals with melting metal and pouring it in liquid form into sand molds to shape it into castings of all descriptions.

In the manufacture of modern machinery three classes of castings are employed, each one having its individual physical properties, such as strength, toughness, durability, etc. These castings are as follows: gray iron; copper alloys, i.e., brass, bronze, etc.; and mild steel. By far the greatest number of castings made are of gray iron, that is, iron which may be machined directly as it comes from the mold without any further heat treatment.

The main purpose of this book is to explain the underlying principles involved in making molds for gray-iron castings, and the mixing and melting of the metals for such castings. The articles on Malleable Cast Iron as well as the articles on Brass Founding and Steel Casting emphasize only those features of the methods used which differ from gray-iron foundry practice. The article on Shop Management is intended to set students thinking on this subject; because the whole trend of modern shop practice is toward specialization and system in handling every department of the work, in order to increase efficiency and reduce cost.

DIVISIONS OF IRON MOLDING

Main Branches. There are four main branches in gray iron molding: (1) green-sand work; (2) core work; (3) dry-sand molding; and (4) loam work.

Green-Sand Molding. The cheapest quickest method of forming the general run of castings is by green-sand molding. Damp molding sand is rammed over the pattern, and suitable flasks are used for handling the mold. When the pattern is withdrawn the

mold is finished, and the metal is poured while the efficiency of the mold is still retained by reason of this dampness. The mold may be poured as soon as made; and in case of necessity it may be held over a day or more depending upon its size. If the sand dries out, the mold should not be poured.

Core Making. Core making supplements molding. It deals with the construction of separate shapes in sand which form holes, cavities, or pockets, in the castings. Such shapes are called *cores.* They are held firmly in position by the sand of the mold itself or by the use of chaplets. Core sand is of a different composition from molding sand. It is shaped in wooden molds called *core boxes.* All cores are baked in an oven before they can be used. The whole detail of their construction is so different from that of a mold, that core making is a distinct trade—a trade, however, that is generally considered a stepping stone to that of molding. Boys usually begin to serve their time in the core shop.

Dry-Sand Molding. Dry-sand molding is the term applied to that class of work where a flask is used, but a layer of core sand mixture is used as a facing next to the pattern and the joint, and the entire mold is baked before pouring. This drives off all moisture and gives hard clean surfaces to shape the iron. It is used where heavy work having considerable detail is to be cast, or where the rush of metal or the bulk of it might injure a mold of green sand. Dry-sand molds are usually made up one day, baked over night, and assembled and cast the next day.

Loam Work. Loam work is the term applied to molds built of bricks carried on heavy iron plates. The facing is put on the bricks in the form of mortar and shaped by sweeps or patterns depending upon the design of the piece to be cast. All parts of the mold are baked, rendering the surfaces hard and clean. After being assembled, these brick molds must be rammed up on the outside with green sand in a pit or casing to prevent their bursting out under the casting pressure. Simple molds can be made up one day, assembled, rammed up and poured the next, but it usually takes 3 or 4 days and sometimes as many weeks to turn out a casting.

Loam work is used for the heaviest class of iron castings for which, on account of the limited number wanted, or the simplicity of the shape, it would not pay to make complete patterns and use a

flask. In some cases the intricacy of the design makes a pattern necessary, and size alone excludes the use of sand and flasks.

Selection of Method. No hard and fast rules exist for the selection of the method by which a piece will be molded. Especially with large work, the question whether it shall be put up in green sand, dry sand, or loam, often depends upon local shop conditions. The point to consider is: How can the best casting for the purpose be made for the least money, considering the facilities at hand to work with?

MOLDING EQUIPMENT

MATERIALS

Before taking up the making of molds, let us consider briefly the materials used, where they are obtained, and what is their particular service in the mold. Also we shall describe the principal tools used by the molder in working up these materials into molds.

Classes. There are three general classes of materials for molding kept in stock in the foundry, as tabulated herewith:

Molding Materials

Sands	Facings	Miscellaneous
Molding sands Light Medium Strong Free sands Sharp or Fire Beach sand	Graphite Charcoal Sea coal	Fire clay Parting dust Burnt sand Charcoal Partainol Core binders

Sands

Quality. All sands are formed by the breaking up of rocks due to the action of natural forces, such as frost, wind, rain, and the action of water.

Fragments of rocks on the mountain sides, broken off by action of frost are washed into mountain streams by rainfall. Here they grind against each other and pieces thus chipped off are carried by the rush of the current down into the rivers. Tumbled along by the rapid current of the upper river, the sand will finally be deposited where the stream flows more gently through the low land stretches

TABLE I

Proportions of Elements in Sands

Elements	Fire Sand (per cent)	Molding Sands				Core Sand (per cent)
		Iron Work			Brass	
		Light (per cent)	Medium (per cent)	Heavy (per cent)	Light (per cent)	
(a) Silica.....SiO_2	98.04	82.21	85.85	88.40	78.86	85.50
Alumina (clay)....Al_2O_3	1.40	9.48	8.37	6.30	7.89	2.65
Iron oxide.....Fe_2O_3	.06	4.25	2.32	2.00	5.45	.85
Lime oxide.....CaO	.20	....	.50	.78	.50	....
(b) Lime carbonate..$CaCO_3$	....	.68	.29	....	1.46	2.65
Magnesia.....MgO	.16	.32	.81	.50	1.18	4.27
Soda.....Na_2O	....	.09	.10	....	.13	.04
Potash.....K_2O	....	.05	.03	....	.09	.04
Combined water....H_2O	.14	2.64	1.68	1.73	3.80	2.00
Organic matter.....		.28	.15	.04	.64	1.00
Specific gravity.....	2.592	2.652	2.645	2.630	2.640	
Degree of fineness.....		85	66	46	95	

below the hills. Here the slight agitation tends to cause the finer sand and the clay to settle lower and lower down in the bed. Thus we find beds that have been formed in ages past; possibly with a top soil formed over them, so long have they been deposited. But on removing this top soil we find gravel or coarse sand on top; this merges into finer sand and this again finally into a bed of clay.

Rocks, however, are very complex in their composition, and sands contain most of the elements of the rocks of which they are fragments. For this reason molding sands in different parts of the United States vary considerably.

A good molding sand first of all, should be refractory, that is, capable of withstanding the heat of molten metal. It should be porous to allow the escape of gases from the mold. It should have a certain amount of clay to give it bond or strength, and should have an even grain. All of these properties will vary according to the class of work for which the sand is used.

Elements. The two important chemical elements in such sands are silica, which is the heat-resisting element, and alumina, or clay, which gives the bond. Other elements which are found in the molding sands are oxide of iron, oxide of lime, lime carbonate, soda potash, combined water, etc. The analyses shown in Table I, made by

W. G. Scott, give an idea of the proportions of these elements in the different foundry sands.

Silica alone is a fire-resisting element, but it has no bond. These other elements help in forming the bond. But under heat, silica combines and fuses with them, forming silicates. These silicates melt at a much lower temperature than does free silica. Therefore with sands carrying much limestone in their make up, or with those containing much oxide of iron, soda potash, etc., the molten iron will burn in more, making it more difficult to clean the casings.

The limestone combinations also go to pieces under heat, tending to make the sand crumble, which may result in dirty castings.

The proportions given in Table I must not be considered as absolutely fixed, for no two samples of sand, even from the same bed, will analyze exactly alike. The table is instructive, however, because it indicates the reasons why the different sands are especially adapted to the use to which they are put in practice.

Fire Sand. Such sand is used in the daubing mixture for repairing inside of cupola and ladles, and should be in the highest degree refractory, and should contain as little matter as possible that would tend to make it fuse or melt.

Light Molding Sand. This sand is used for castings such as stove plate, etc., which may have very finely carved detail on their surfaces, but are thin. The sand should be very fine to bring out this detail; it must be strong, i.e., high in clay, so that the mold will retain every detail as the metal rushes in. On the other hand, the work will cool so quickly that after the initial escape of the air and steam there will be very little gas to come off through the sand.

Medium Sand. Sand of this grade is used in bench work and light floor work, for making machinery castings having from $\frac{1}{2}$- to 2-inch sections. These will have less fine detail, so the sand may be coarser than in the previous case. The bond should still be fairly strong to preserve the shape of the mold, but the tendency of the large proportion of clay to choke the vent will be offset by the larger size of the grain. This vent must be provided for because the metal will remain hot in the mold for a longer time and will cause gases to form during the whole of its cooling period.

Heavy Sand. This grade of sand is used for the largest iron castings. Here the sand must be high in silica and the grain coarse,

because the heat of the molten metal must be resisted by the sand, and gases must be carried off through the sand for a very long time after pouring. The amount of bond or clay must be small or it will cause the sand to cake and choke these gases. The detail is generally so large that the lack of bond is compensated for by the use of gaggers, nails, etc. The coarse grain is rendered smooth on the mold surface by careful slicking.

Core Sand. Core sand, often almost entirely surrounded by metal, must be quite refractory but have very little clay bond. This bond would make the sand cake, choking the vent, and render it difficult of removal from a cavity when cleaning the casting. Compared with medium molding sand, it shows higher in silica, although having less than half the proportion of alumina.

Free Sands. Sands having practically no clay in them are called *free sands*. Of these there are two kinds in use: river sands, and beach sands.

River Sand. The grains of river sand retain the sharp fractured appearance of chipped rock, and these little sharp grains help much in making a strong core because the sharp angular grains interlock one with another. River sand is used on the larger core work.

Beach Sand. Beach sand is considerably used in coast sections because it is relatively inexpensive, but its grains are all rounded smooth by the incessant action of the waves. It will pack together only as will so many minute marbles. For this reason it is used only for small cores.

Facings

Function. *Foundry facing* is the term given to materials applied to or mixed with the sand which comes in contact with the melted metal. The object is to give a smooth surface to the casting. They accomplish this in two ways: (1) by filling in the pores between the sand, thus giving a smooth surface to the mold face before the metal is poured; and (2) by burning very slowly under the heat of the metal, forming a thin film of gas between the sand and iron during the cooling process. This prevents the iron burning into the sand and causes the sand to separate from the casting when cold.

Different forms of carbon are used for this purpose because carbon will glow and give off gases, but it will not melt. The principal facings are graphite, charcoal, and sea coal.

Graphite. Graphite is a mineral form of carbon. It is mined from the earth and shipped in lumps which are blacker than coal and are soft and greasy like a lump of clay. The purest graphite comes from the Island of Ceylon, India. There are several beds, however, in the coal fields of North America.

Charcoal. Charcoal is a vegetable form of carbon. It is made by forming a shapely pile of wood, covering this over with earth and sod, with the exception of four small openings at the bottom and one at the top. The pile is set on fire and the wood smoulders for days. This burns off the gases from the wood, leaving the fibrous structure charred but not consumed. Charcoal burning is done in the lumbering districts. The charcoal for foundry facings should be made from hard wood.

Sea Coal. Although sea coal contains a high per cent of carbon, it is less pure than the other facings and gives off much more gas. Sea coal is made from the screenings from the soft-coal breakers. The coal should be carefully selected by the manufacturer and be free from slate and very low in sulphur.

Distinction. All facings are manufactured by putting the raw materials through a series of crushers, tumbling mills, or old-fashioned burr stone mills, and then screening them. The finest facings are bolted much as flour is.

In the shop the molder distinguishes between facings or blackings, and facing sand. *Blacking* consists of graphite or charcoal, and is applied to the finished surface of a mold or core. *Facing sand* is the name given to a mixture of new sand, old sand, and sea coal, which in the heavier classes of work forms the first layer of sand next the pattern.

The use of the different facings will be clearly seen from the tabulation on page 8.

Miscellaneous Materials

Fire Clay. Fire clay comes from the same source that sand does. It is almost pure oxide of alumina, which is separated out from the sand by a combination of the chemical action of the waters of the streams. Fire clay has traces of the other impurities men-

Characteristics of Facings

Material	Uses	Action
Charcoal	Good facing for light molds; dusted on from bag after pattern is drawn. Mixed with molasses water for wash for small cores and dry-sand work. Mixed with some graphite and clay wash for blacking for heavy dry-sand and loam work; slicked over with tools. May be used as a parting dust on joint of bench molds.	Burns at low enough temperature to be effective before thin work cools. Resists moisture; prevents sand surfaces from sticking together.
Graphite	Good facing for bench molds; dusted on from bag; good for medium and heavy green-sand work. Applied with camel's hair brush, and slicked over with tools. As heavy blacking for dry-sand and loam work, used as above.	Good on heavier green sand because it is more refractory than charcoal, but still forms gas enough to keep metal from burning into sand.
Sea Coal	Mixed with facing sand in proportions from 1:6 to 1:12. See section on Molding.	Helps to force vents through sand when mold is first poured, and prevents strong sand of the facing from caking, because it continues to throw off gas after casting has solidified.

tioned in the analysis of molding sands. It is found in the lowest strata of the deposit beds. It is used to mix with fire sand in the proportion of 1 to 4 as the daubing mixture for cupola and ladles.

Clay wash is a mixture of fire clay and water. The test for mixing it is to dip the finger into the wash and then withdraw it, whereupon there should be an even film of clay deposited on the finger. Clay wash is used as the basis of heavy blackings. It is used as follows: for wetting crossbars of flasks; for breaks in sand where a repair is to be made; to wet up the dry edges of ladle linings when repairing with fresh daubing mixture; in fact, any place where a strong bond is required at some particular spot.

Parting Dusts. Parting sands or parting dusts must contain no bond. They are used to throw on to the damp surfaces of molds which must separate one from another. They prevent these surfaces formed of high bond sands from sticking to each other.

The cheapest parting sand, and by far the most commonly used, is obtained by putting some burnt core sand, from the cleaning shed, through a fine sieve.

Beach sand is also used as a parting sand, but the rounded nature of its grain weakens the molding sands more than does burnt core sand.

Charcoal facing dusted from a bag makes an excellent parting dust on fine work.

A dust manufactured expressly for the purpose and called "Partainol" is the most perfect material for fine work. This is applied from a dust bag. It is not only useful for sand joints, but is a great help if there is a deep lift on a pattern where the sand is liable to stick, or for a troublesome box in the core room.

Core Binders. Although the materials for this purpose—flour, rosin, oil, etc.—are on the purchasing list of the general foundry buyer, for the purposes of this article they will be explained in detail under Core Work.

TOOLS

Under this heading only the hand tools and equipment used by the molder in putting up his mold are described. The mechanical appliances for reducing labor are described in a later section.

Flasks. To use sand economically for molds, sets of open frames called *flasks* are used. Flasks consist of two or more such boxes. The lower box is called the *drag* or *nowel*, the upper box is called the *cope*. If there are intermediate parts to the flask they are called *cheeks*. Flasks are fitted with pins and sockets so that they will always register.

Snap Flask. For small castings the molds are rammed up on benches or projecting brackets. Such work is termed *bench work* and the flasks are usually what are known as *snap flasks*. They range in size from 9 by 12 inches to 18 by 20 inches. As is seen in Fig. 1, these flasks hinge on one corner and have catches on the diagonal corner. The advantage of the snap flask is that any number of molds may be put up with but one flask, and the flask removed as each mold is completed. There are several good snap flasks to be had on the market. Many foundries, however, make up their own.

Each size of flask should have at least one smooth straight board called the *mold board*, the size of outside dimensions of the flask.

Rough boards or bottom boards of same size should be provided, one for each mold that will be put up in a day.

Boards for snap work are made of from $\frac{7}{8}$- to 1-inch stuff, and should have two stiff cleats, as shown in Fig. 2, to hold them straight.

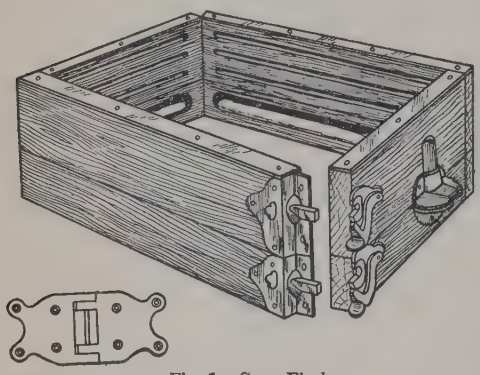


Fig. 1. Snap Flask

Wood Flask. For heavier castings where the molds are made on the floor, box flasks are used made of wood or iron.

In the jobbing shop, wood flasks are more economical, as they can more readily be altered to fit a variety of patterns, while in a foundry turning out a regular line of castings, iron flasks pay because they require less repair.

Wooden flasks of necessity receive hard usage in the shop and grow weaker each time they are used. They will burn more or less each heat; they receive rough usage when the mold is shaken out; and often the flasks must be stored where they are exposed to all kinds of weather. It is economy, therefore, to build wooden flasks heavier than would be necessary if they were always to be used in their new condition.

Fig. 3 shows the construction of a typical wooden flask; the sides project to form lifting handles; the ends are gained in to the sides. Through bolts, in addition to the nailing, hold the sides firmly. A detail of the pin is shown at *A*, and at *B* is a cast-iron rocker useful on flasks over 4 by 5 feet, to facilitate lifting and rolling over. The cleats make it a simple matter to alter crossbars. The crossbars should be not over 8 inches on centers. For more than 3-foot spans they should have short crossbars through the middle connecting the long ones. In flasks 4 feet and over there should be one or more iron crossbars and a $\frac{1}{2}$-inch through bolt with good washers to clamp the sides firmly to them.

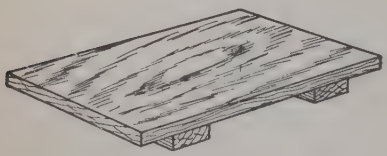


Fig. 2. Mold Board

TABLE II

Sizes of Wooden Flasks

Flask Sizes (6 inches deep)	Material			
	Sizes		Arrangement	
	Sides (inches)	Cross-bars (inches)	Short Cross-bars (rows)	Iron Cross-bars (number)
Up to 24 by 24 in.	1½	1		
18 in. to 24 in. wide up to 5 ft. long	2	1		1
24 in. to 36 in. wide up to 6 ft. long	2½	1¼	1	2
36 in. to 48 in. wide up to 7 ft. long	3	1½	2	2

Note. For each additional 6-inch depth of cope or drag add 25 per cent to the thickness given.

Table II shows thickness of stuff for sides and crossbars for average sizes of jobbing flasks.

Illustrative Example. Find thickness of sides and bars in a flask 30 by 48 inches.

By referring to Table II, it is noted that for lengths on the sides over 2 feet and under 5 feet the thickness of *sides* should be 2 inches.

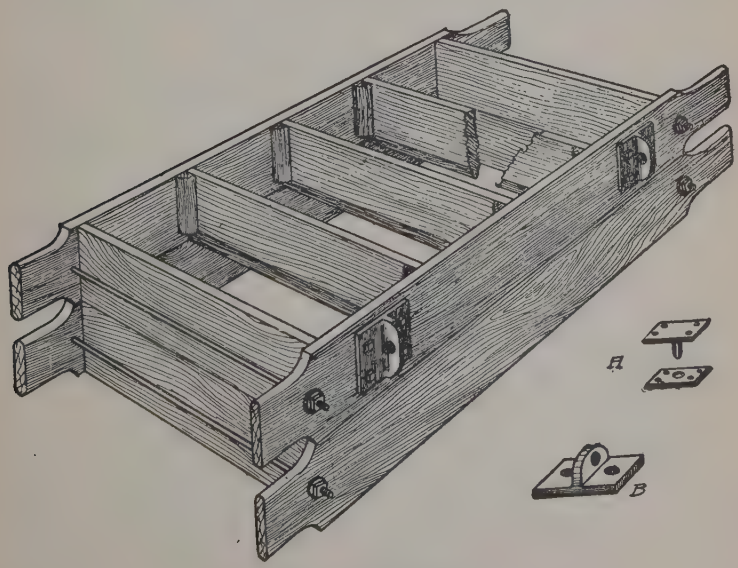


Fig. 3. Wooden Flask

Similarly, for widths of flask of over 24 inches and under 36 inches, the thickness of *crossbars* should be 1¼ inches.

Iron Flask. In Fig. 4 is shown the construction of a large iron flask suitable for dry-sand work. The pieces of the flask are usually cast in open sand from a skeleton pattern, all holes cored in. The crossbars are cast in the same way; they have a slot in the flange instead of holes to facilitate adjusting them. Trunnions and rockers are sometimes cast on the sides in a core instead of being made separate and bolted on. Holes for pins are usually drilled through the joint flange. For pins, short iron bars are used temporarily in

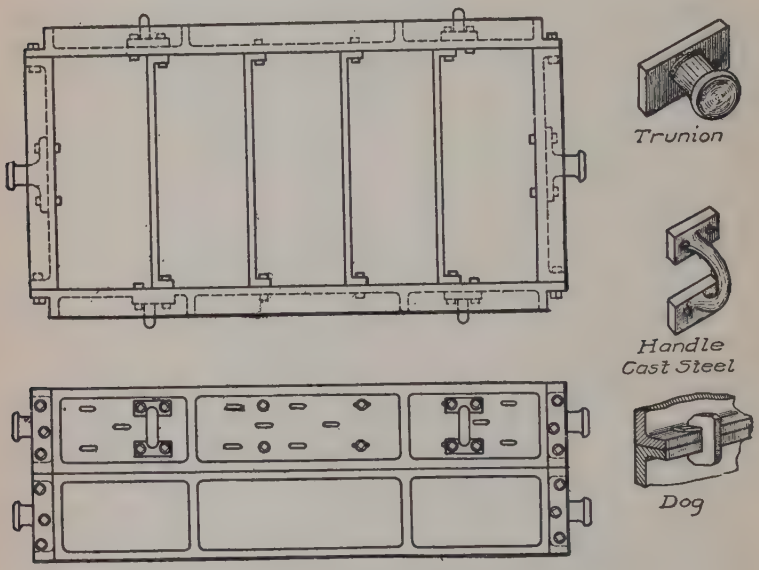


Fig. 4. Iron Flask

closing. The thickness of metal varies from $\frac{7}{8}$ inch to $1\frac{1}{4}$ inches, according to size of flask.

In Fig. 5 is shown a typical form of iron flask used on some molding machines. The boxes are cast in one piece. The handles serve as lugs for the closing pins. Only one pin is fixed on each box. This makes the boxes interchangeable and capable of being used for either cope or drag.

Shovel. For cutting and handling loose sand the molder uses a shovel with flat blade, as in Fig. 6, for it is often more convenient to let the sand slide off of the side of the shovel than off of the end.

This is especially true when shoveling sand into bench molds or molding-machine flasks.

Sieve. The foundry sieve or riddle, Fig. 7, is used to break up and remove lumps, shot iron, nails, etc., from the sand placed next the pattern or joint. Sieves should have oak rims with brass or galvanized-iron wire cloth. In ordering, the diameter of rim and the number of meshes to the inch of the woven wire is given. Good sizes for the iron foundry are 16 inches to 18 inches diameter, No. 8 to 12 on bench work, No. 4 to 8 on floor work.

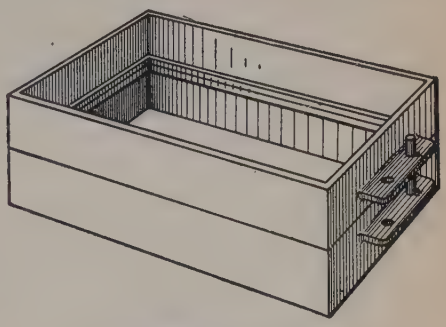


Fig. 5. Flask for Molding Machine

Rammers. Rammers are used for evenly and quickly packing the sand in the flask. One end is in the shape of a dull wedge, called the peen end, the other is round and flat called the butt end. Of the rammers shown in Fig. 8, *a* is the type used on bench work; *b* is a floor rammer having cast heads and wooden shaft; *c* shows a rammer made up in the foundry by casting the heads on the ends of an iron bar; *d* shows a small peen cast on a short rod—this is convenient for getting into corners or pockets on floor work.

Fig. 6. Flat Blade Shovel

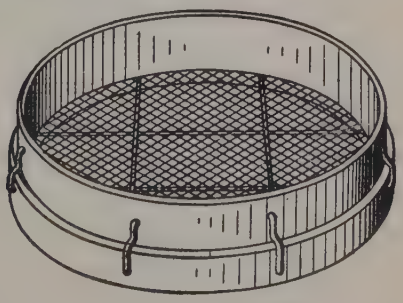


Fig. 7. Foundry Sieve

Pneumatic Type. In shops equipped with compressed air a pneumatic rammer, as shown in Fig. 9, is sometimes used to butt off large flasks, and for ramming loam molds in pits.

Finishing Tools. Molders' tools are designed for shaping and slicking the joint surfaces of a mold and for finishing the faces of the mold itself. Excepting the trowels, they are forged in one piece

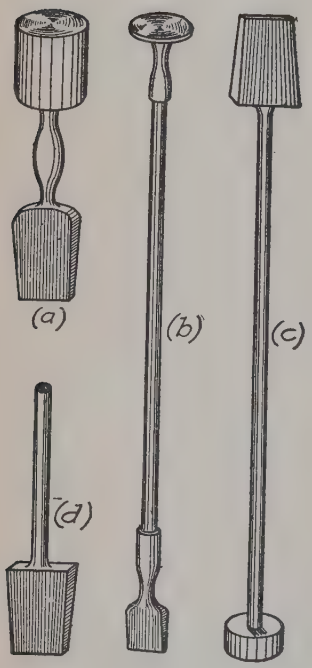


Fig. 8. Rammers

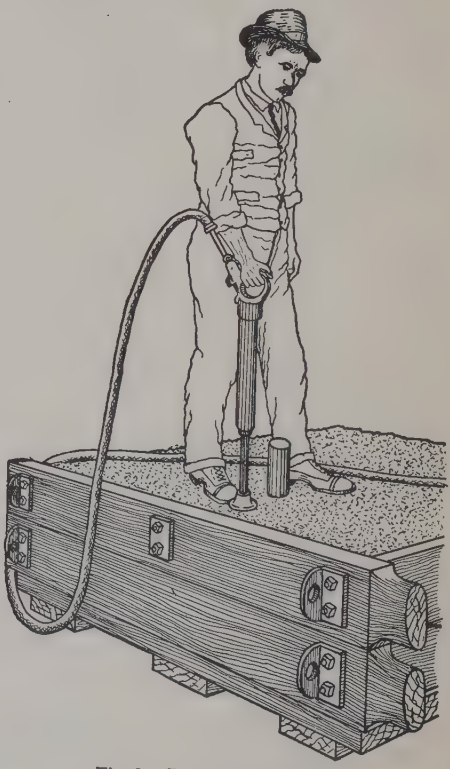


Fig. 9. Pneumatic Rammers

from steel. The trowels have steel blades and short round handles which fit conveniently into the grasp of the hand. All of the tools are ground slightly crowning on the bottom, and they are rocked just a little as they are worked back and forth over the sand to prevent the forward edge cutting into the surface of the mold.

Of the sixty or more combinations of shapes on the market, the few illustrated represent the ones most commonly used in jobbing shops.

Trowels. Trowels, Fig. 10, are used for shaping and smoothing the larger surfaces of a mold. The square trowel *a* is convenient for working up into a square corner, and the finishing trowels *b* and *c*

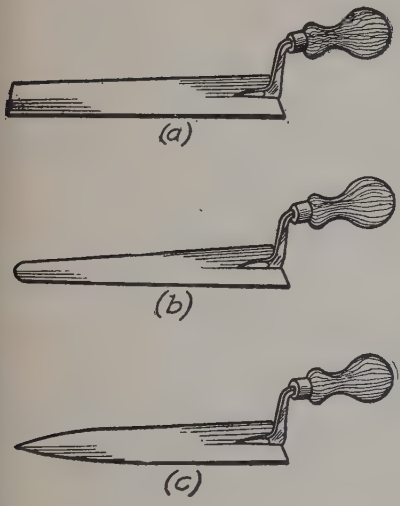


Fig. 10. Trowels

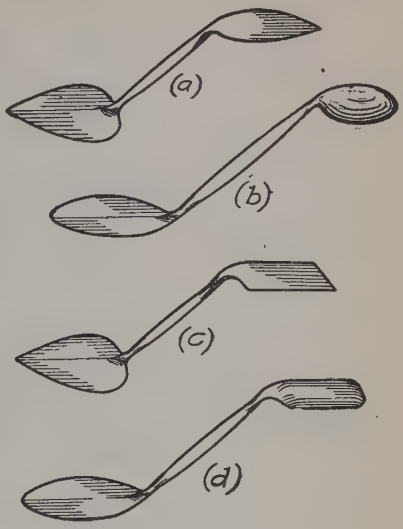


Fig. 11. Slicks

are more for coping out and finishing along the curved edges of a pattern. Trowels are measured by the width and length of blade.

Slicks. Slicks are designated by the shape of the blade and the width of the widest blade. In Fig. 11, *a* is a heart and leaf; *b* is a

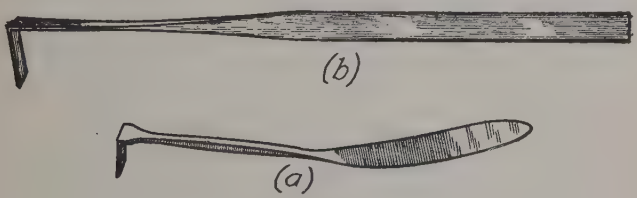


Fig. 12. Lifters

leaf and spoon; *c* is a heart and square; and *d* is a spoon and bead. These are in sizes of 1 inch to $1\frac{3}{4}$ inches. They are used for repairing and slicking small surfaces.

Lifters. Fig. 12 shows lifters used to clean and finish the bottom and sides of deep narrow openings; *a* is a floor lifter, made in

sizes from $\frac{1}{8}$- by 10-inch to 1- by 20-inch; *b* is a bench lifter, the sizes of which vary from $\frac{3}{16}$ inch to $\frac{3}{4}$ inch wide.

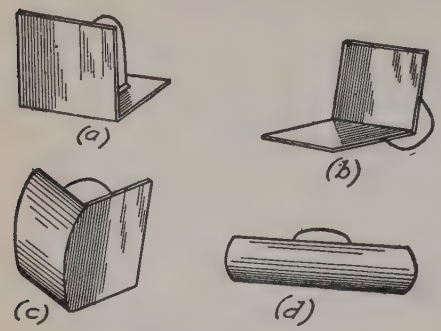


Fig. 13. Square Corner Slicks

Corner Slicks. Fig. 13 shows at *a* and *b* inside and outside square-corner slicks, made in sizes of 1 to 3 inches; *c* is a half-round corner, widths 1 inch to $2\frac{1}{2}$ inches; and *d* is a pipe slick made 1 inch to 2 inches. This style of tool is mainly used on dry sand and loam work.

Swabs. Swabs are used to moisten the edges of the sand about a pattern before drawing it from the mold. This foundry swab is a dangerous though useful tool. Its danger lies in the too free use of water around the mold, which may result in blowholes. A good swab for bench work is made by fastening a piece of sponge, about double the size of an egg, to a goose quill or even a pointed hardwood stick. The point will act as a guide and the water may be made to run or simply drop from the point by varying the pressure on the sponge.

Fig. 14. Floor Swab

Floor swabs, Fig. 14, are made from hemp fiber. They should have a good body of fiber shaped to a point, and should be made about 12 inches or 14 inches long. They will take up considerable water and deliver it from the tip of the point. In heavy work the swab is trailed lightly over the sand like a long bristled brush.

Fig. 15. Vent Rod

Vent Rods. Vent wires are used to pierce small holes through the sand connecting the mold cavity with the outside air. For bench work a knitting needle is the most convenient thing to use. It should have a short hardwood handle or cast ball on one end. Select a needle as small as possible, so long as it will not bend when using it.

Heavy vent rods are best made, as shown in Fig. 15, of a spring steel from $\frac{3}{16}$ inch to $\frac{1}{2}$ inch with the pointed end enlarged a little to give clearance for the body of the rod when run deep into the sand.

Draw Sticks. Draw sticks are used to rap and draw patterns from the sand. In Fig. 16 are shown three kinds: *a* is a small pointed rod $\frac{1}{4}$ inch to $\frac{3}{8}$ inch in size, which gets its hold by simply driving it into the wood of the pattern; *b* is a wood screw welded to an eye for convenience; *c* is an eye rod with machine-screw thread, which requires a metal plate let into the pattern. The plate is called a *rapping plate* and is made with separate holes not threaded, into which a pointed rapping bar is placed when rapping the pattern, thus preserving the threads used for the drawbar.

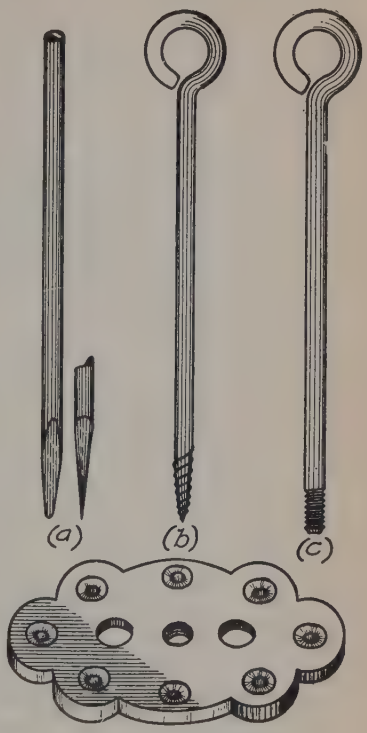


Fig. 16. Draw Sticks

Clamps. In pouring, the parts of a mold must be clamped by some method to prevent the pressure of the liquid metal from separating them, causing a run-out. For light work a weight such as shown in Fig. 17 is the most convenient. This is simply a plate of cast iron 1 inch to $1\frac{1}{2}$ inches thick, with a cross-shaped opening cast in it to give considerable liberty in placing the runner in the mold. The weights are from 15 to 40 pounds, according to size of flasks.

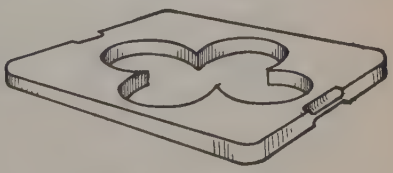


Fig. 17. Weight

Floor flasks are fastened with clamps made of cast iron which are tightened by prying them on to a hardwood wedge. In Fig. 18 is shown how the wedge may first be entered and how the clamping bar is used to firmly clamp the flask. For iron flask

used in dry-sand work the clamps are very short, as only the flanges are clamped together, as may be seen in Fig. 4. In that connection iron wedges are used instead of wood. Often the iron bottom board is clamped on and the joint flanges bolted together before pouring.

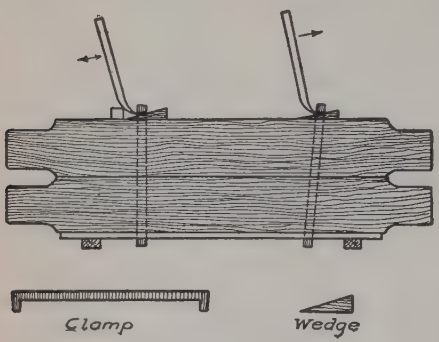


Fig. 18. Illustrating Method of Clamping

MOLDING PROCESSES

PRINCIPLES OF GREEN-SAND MOLDING

Good Work. There are certain principles underlying iron molding which hold good in all classes of founding, and a practical understanding of these principles is necessary for good work in any line.

Aside from the fact that generally a mold is wanted which takes the least possible time to put up, three things aimed at in green-sand work are: (1) a sound casting, which is free from internal imperfections, such as blow holes, porous spots, shrinkage cracks, etc.; (2) a clean casting, which is free from dirt, such as slag, sand, etc.; and (3) a smooth casting, having a uniform surface free from scabs, buckles, cold-shuts, or swells.

Sand Mixture. The natural sands best adapted to obtain these results have already been dealt with. The methods of adding new sands vary with different classes of work. For light work the entire heap should be kept in good condition by adding a little new sand every day, for the light castings do not burn out the sand to a great extent.

On heavier work of 50 pounds and upward, the proportion of sand next the pattern is so small compared with that used simply to fill the flask, that it does not pay to keep the entire heap strong enough for actual facing. The heap should be freshened occasionally with a cheap molding sand, but for that portion of the mold which forms the joint surface, and especially that which comes in contact with the metal, a facing sand should be used.

The range of new sand in facing mixtures on a 10-part basis, with sea coal in addition, is as tabulated herewith:

Proportions of Facing Mixtures

(Basis of 10 Parts)

Sand			Sea Coal (additional part)
New	Old	Free	
3—6	6—2	1—2	$\frac{1}{6}$—$\frac{1}{8}$

These proportions, and the thickness of the layer of facing sand, vary with the weight of metal in the casting. Too much new sand tends to choke the vent and to cause sand to cake; too little new sand renders facing liable to cut or scab. Too much sea coal makes sand brittle and more difficult to work, and also gives off too much gas which is liable to cause blowholes in casting. Not enough sea coal allows the sand to cake, making cleaning difficult.

Tempering and Cutting. To prepare foundry sand for making a mold, it must be tempered and cut through. This is now usually done by laborers. To temper the sand, throw water over the heap in the form of a sheet by giving a peculiar backward swing to the pail as the water leaves it. Then cut the pile through, a shovelful at a time, letting the air through the sand and breaking up the lumps. This moistens the clay in the sand, making it adhesive and puts the pile in the best condition for working.

To test the temper, give one squeeze to a handful of sand. An excess of water will at once be detected by the soggy feeling of the sand. Now hold the egg-shaped lump between thumb and finger of each hand and break it in the middle. The edges of the break should remain firm and not crumble. Too much moisture will make excess of steam in the mold, causing blowholes. Not enough moisture renders sand weak and apt to wash or cut.

Bearing in mind the nature of the materials we have to work with, we must now study the important operations involved in making a sand mold.

Sifting. The sand next to the joint and over the pattern should be sifted. The thickness of this layer of sifted sand varies from about $\frac{3}{4}$ inch for light work to 2 inches on very heavy work. The fineness of the sieve used depends upon the class of work. No. 16 or 12 would be used for small name plates, stove plate, etc., while

No. 8 or 6 is good for general machinery work. On floor work, from 4 to 6 inches of sand back of the facing should be riddled through a No. 4 sieve to ensure more even ramming and venting.

Ramming. The object of ramming is to make the sand hang into the flask and to support the walls of the mold against the flow and pressure of the metal. The knack of ramming just right only

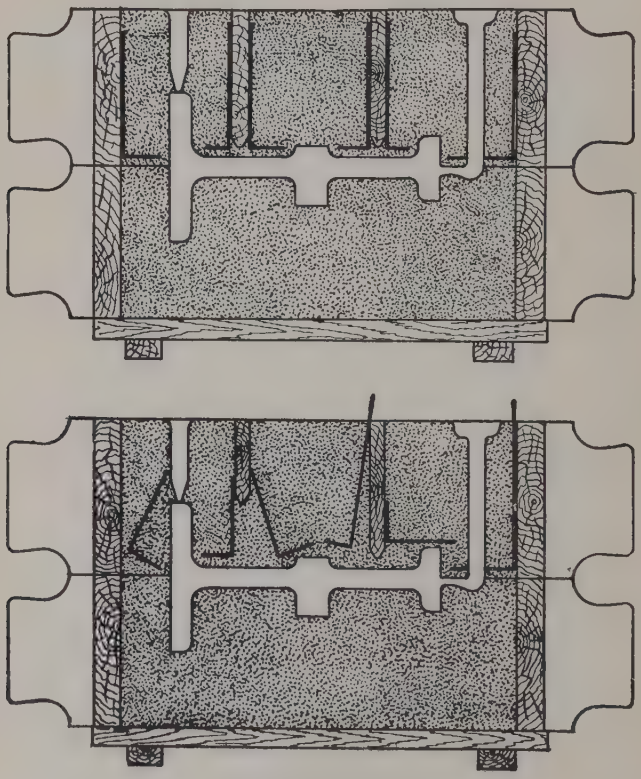


Fig. 19. Setting Gaggers

comes with continued practice and comparison of results. Hard ramming closes up the vent, causing blowholes. Iron will not "lay" into a hard surface. Soft ramming leaves a weak mold surface, and the flow of the metal as it enters the mold washes or cuts the sand, leaving a scab on one part of the casting and sand holes on another. A mold rammed too soft tends to swell under the pressure of the liquid metal, making the casting larger than the

pattern or leaving an unsightly lump on the casting. The bottom parts of a mold, being under greater casting pressure, must be rammed somewhat harder than the upper portions. The joint also should be packed firmly, as it is exposed to more handling than any other part.

Gaggers. Crossbars are put in the cope to make it possible to lift the sand with the cope without excessively hard ramming. As an additional support for the cope sand on large work there are

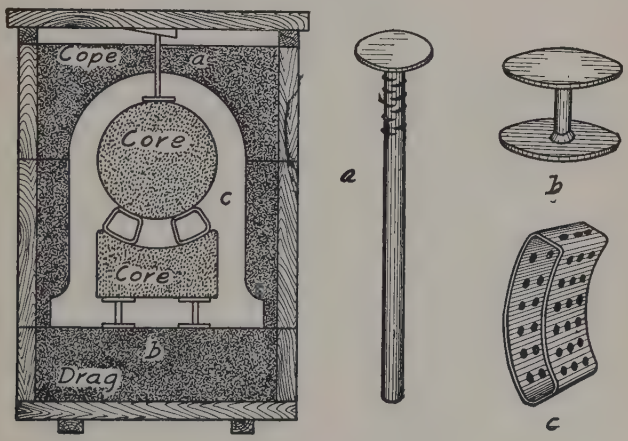


Fig. 20. Chaplets

used gaggers, which are L-shaped pieces of iron made from wrought or cast iron of from $\frac{5}{16}$-inch to $\frac{1}{2}$-inch square section.

The force of sand pressing against the long leg of the gagger holds it in place and the short leg supports the sand about it. Therefore the gagger will hold best when the long leg is placed tight against the crossbar and is plumb. The long leg of the gagger should not project above the level of the cope, as there is much danger of striking it and breaking in the mold after the flask is closed. In Fig. 19 are shown the right and wrong ways of setting gaggers.

Use of Chaplets. Chaplets should be used to support parts of cores which cannot be entirely secured by their prints which are held in the sand of the mold. In Fig. 20 are shown the three principal forms of chaplets used, and how they are set in the mold; *a* is a stem chaplet; *b* is a double-headed or stud chaplet; and *c* is a form of chaplet made up of strip metal.

That portion of the chaplets which is to be bedded in metal is tinned to preserve it from rusting, because rusty iron will cause liquid metal to blow. For small cores nails are often employed for this purpose, but only new ones should be used. With the stem chaplets the tails must be cut off when the casting is cleaned—the stud chaplet becomes entirely embedded in the metal. There are now manufactured and on the market many different styles of chaplets. In selecting the size and form for a given purpose the head of the chaplet should be large enough to support the weight of the core without crushing into the sand and thin enough to fuse into the liquid metal. The stem must be small enough to fuse well to the metal and stiff enough, when hot, not to bend under its load.

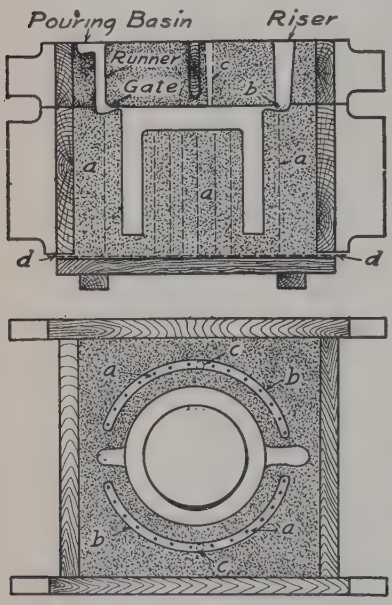


Fig. 21. Use of Risers

Venting. In the section on Sands reference has already been made to gases which must be taken off from a mold when it is poured. There are three forms of these: (1) air, with which the mold cavity is filled before pouring; (2) steam, formed by the action of the hot metal against the damp sand during the pouring process; and (3) gases formed while the casting is cooling, from chemical reactions within the liquid metal and from the burning of organic matter, facings, core binder, etc., in the sands of the mold. It is of the greatest importance that these gases pass off quickly and as completely as possible. If they do not find free escape through the mold they are forced back into the liquid metal, making it boil or blow. This may blow the metal out through risers and runners, or simply form numerous little bubble-shaped cavities in the casting, called *blowholes*. These often form just below the skin of the casting and are not discovered until the piece is partially finished.

Various Systems. One cannot depend entirely upon the porosity of the molding sands, but must provide channels or vents for the escape of these gases. For light work a free use of the vent wire through the sand in the cope will answer all purposes.

On castings of medium weight, besides venting with the wire, risers are placed directly on the casting or just off to one side as shown in Figs. 19 and 21. These are left open when the mold is poured and provide mainly for the escape of the air from the mold.

Heavy castings that will take time to cool, and thus keep facings burning for a long time after the mold is poured, require venting on sides and bottom as well as top. Fig. 21 shows side vents *aaaa* connecting with the air through the channel *bbb* cut along joint and risers *ccc* passing through the cope. At the bottom the vents connect with cross-vents *dd* run from side to side between the bottom board and edge of flask. Fig. 22 shows a mold bedded in the floor; the side or down vents connect at the top, as in previous examples, and at the bottom with a cinder bed about 2 inches thick, rammed over entire bottom of pit. The gases find escape from this cinder bed through a large gas pipe.

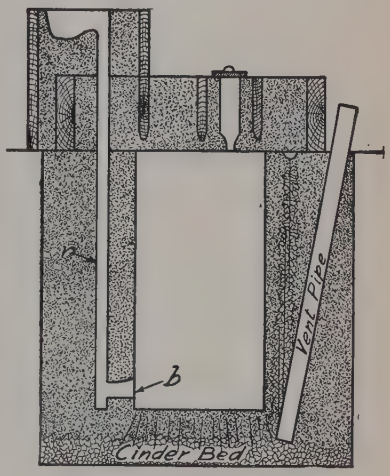


Fig. 22. Mold Bedded in Floor

Action During Pouring. In pouring, the gas from vents should be lighted as soon as may be. The burning at the mouths of vents helps to draw the gases from below and also keeps the poisonous gas out of the shop.

It is customary to keep risers closed with small cover plates when large castings are being poured so that the air in the mold will be compressed as the metal rises in the mold. This helps sustain the walls of the mold and forces the vents clear so that they will act more quickly when the mold is full. These covers are removed occasionally to watch the progress of pouring, and are entirely removed when the metal enters the risers.

Gating. *Gating* is the term applied to the methods of forming openings and channels in the sand by which liquid metal may enter the mold cavity. The terms *sprues* and *runners* are also used in the same connection in some shops.

Functions of Parts. There are practically three parts to all gates: pouring basin; runners; and gate, as seen in Fig. 21. The runner is formed by a wooden gate plug made for the purpose. The pouring basin is shaped by hand on top of the cope, and the gate proper is cut along the joint surface by means of a gate cutter. In all cases the gate section should be smaller than any other part so that, when pouring, the runner and basin may be quickly flooded; also that the gate when cold will break off close to the casting and lessen the work of cleaning.

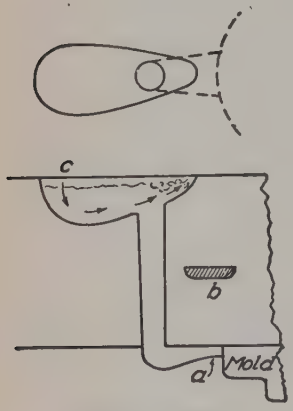


Fig. 23. Gate

The object of gating is to fill the mold cavity with clean metal—to fill it quickly, and while filling, to create as little disturbance as possible in the metal.

The impurities in liquid metal are lighter than the metal itself, and they always rise to the top when the melted metal is at rest or nearly so. Advantage is taken of this important property to accomplish the first of the objects mentioned.

Fig 23 shows a good type of gate to use on light work. For reasons given, the point *a* should have the smallest sectional area. This section should be wider than it is deep as shown at *b*, because the hot iron necessary for light work runs very fluid.

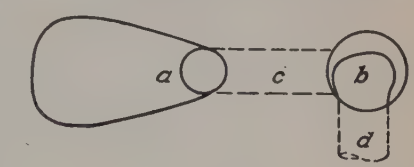
The runner should not be more than $\frac{5}{8}$ to $\frac{3}{4}$ inch in diameter. The pouring basin should be made deepest at point *c*, and slant upward crossing the runner. When pouring, the stream from the ladle should enter at *c*, flood the basin at once, and keep it in this condition. The current of the metal will then tend to hold back the slag, allowing clean metal to flow down the runner.

Skimming Gate. When particularly clean castings of medium weight are required, some form of skimming gate should be used. Fig. 24 illustrates one of several practical forms. They all depend

for their efficiency upon the principle cited. In the illustration, *a* is the pouring basin and runner, *b* is a good sized riser placed about 3 or 4 inches from *a*, and *c* is a channel cut in the cope joint, connecting these two. The gate *d* should be cut in the drag side of the joint, just under the riser but at a right angle with the direction of *c*. The metal rushing down the runner is checked by the small size of the gate and so washes any dirt or slag up into the large riser *b*. The level of metal in this riser must be sustained by sufficiently rapid pouring until the mold is filled.

In bench work and floor work, the greatest care must be used to have all parts of the gate absolutely free from loose sand or facing which would wash into the mold with the first flood of metal.

On heavy work special skimming gates are not used, for the capacity of the pouring basin is very much greater than that of the runners which can be quickly flooded and thus retain the slag. Besides this, large risers are set at the sides or directly upon the casting, to receive any loose sand or facing that washes up as the mold is being filled. Fig. 22 illustrates this type.



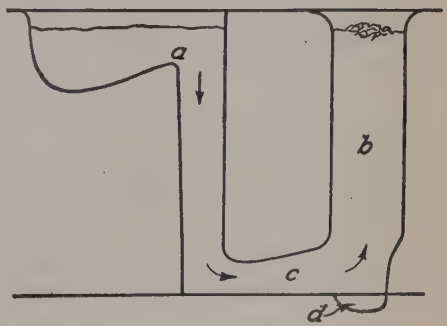


Fig. 24. Skimming Gate

Important Conditions. As regards the filling of the mold quickly and quietly, these two conditions are closely allied. The shape and thickness of the casting are the important factors in determining the number and position of the gates. Aside from the fact that the gate should never be heavier than the part of the casting to which it attaches, the actual size of the gate opening is something that the molder must learn from experience.

In arranging gates with regard to the shape of the pattern, the following points should be borne in mind: Place gates where

the natural flow of the metal will tend to fill the mold quickly. Usually gate on the lighter sections of the casting. Select such points on the casting that the gates may be broken and ground off with least trouble—the greater the number of castings to be handled, the more important this point becomes. A study of the molding problems given will illustrate this point.

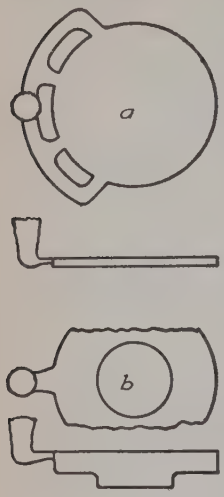


Fig. 25. Use of Gates

Provide enough gates to fill all parts of the mold with metal of uniform temperature. This depends upon the thickness of the work, as is illustrated in Fig. 25 by two molds having the same shape at the joints but of different thicknesses. In thin castings the metal tends to chill quickly, so it must be well distributed. In this illustration, *a* is a plate $\frac{1}{4}$ inch thick, and should have several gates. A piece having the same diameter but heavier, would run better from one gate as at *b*, while if a bushing of this diameter is required, the best results would be obtained by gating near the bottom, as in Fig. 22. For running work at the bottom as shown in Fig. 22, the gate piece *b* is separate from the runner, and is slicked into the mold after the pattern is drawn. The runner *r* should extend below the level of the gate to receive the force of the first fall of metal, which otherwise would tend to cut the sand of the gate.

Fig. 26. Sinking of Casting

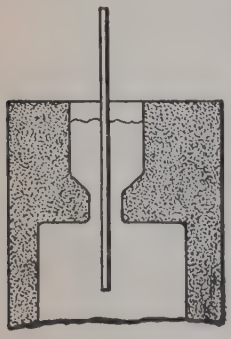


Fig. 27. Feeding Rod

Shrinkage Heads. Melted metal shrinks as it cools, and this process begins from the moment the mold is filled. The surfaces next to the damp sand are the first to solidify, and they draw to themselves the more fluid metal from the interior. This process goes on until the whole casting has solidified. This shrinkage causes the grain in the middle to be coarse and sometimes even open or porous.

The lower parts of a casting are under the pressure or weight

of all the metal above, and so resist these shrinkage strains. The top parts, however, require the pressure of liquid metal in gates or risers to sustain them until they have hardened sufficiently to hold their shape, or they will sink as indicated by the section, Fig. 26. Risers, mentioned in connection with securing clean metal, are also required on heavy pieces to prevent this distortion and to give sound metal. When used in this way they are called *shrinkage heads* or *feeders*. They should be 6 or 8 inches in diameter, so as to keep the iron liquid as long as possible, and should have a neck 2 or 3 inches in diameter, to reduce the labor required to break them from the casting in cleaning. To prevent the metal in this neck from freezing, an iron feeding rod is inserted, as in Fig. 27, and is churned slowly up and down. This insures fluid metal reaching the interior. As the level in the feeder lowers, hot metal should be added from a hand ladle.

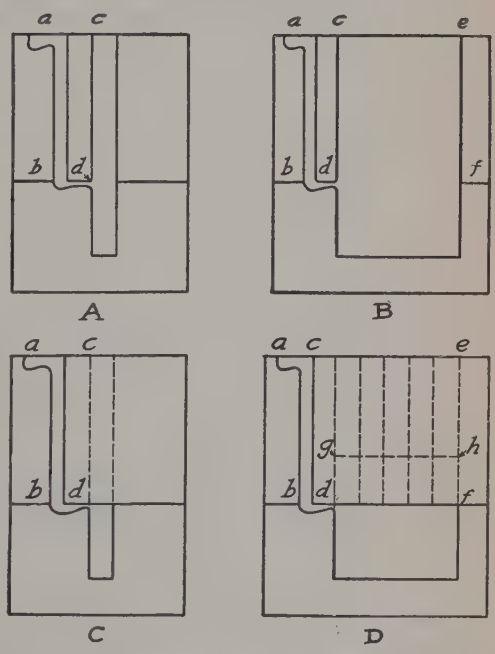


Fig. 28. Illustrating Pressure of Liquids in Molds

Pressure in Molds. The subject of the pressure of liquid iron mentioned repeatedly in the foregoing pages, must be dealt with by the molder, in weighting his copes, strengthening flasks, securing cores, etc., and most frequently in connection with the first-of these.

Natural Laws. Molten iron acts in accordance with the same natural laws that govern all liquids—as, for example, water (see Mechanics, Part II); iron, however, is 7.2 times heavier than water. The two laws applicable in foundry work are these: (1) Liquids always seek their own level; (2) pressure in liquids is exerted in every direction.

Pressure-Head Example. Applying the first law, if we have two columns of liquid iron connected at the bottom, they would just balance each other. For convenience we shall leave out of our calculations the upward pressure on the gates in the following examples, for in practical work they need seldom be taken into account.

In *A*, Fig. 28, suppose these columns stand 6 inches above the joint *bd*, and that the column *cd*, has an area of 1 square inch. In *B*, suppose the area of the right-hand column *cdef* is 5 times the area of column *cd*. In both cases the level with top of runner *a* will be maintained. The depth of the cavity below the joint *bdf* makes no difference in maintaining these levels. The weight of one cubic inch of iron, .26 pound, is taken as the basis of all calculations.

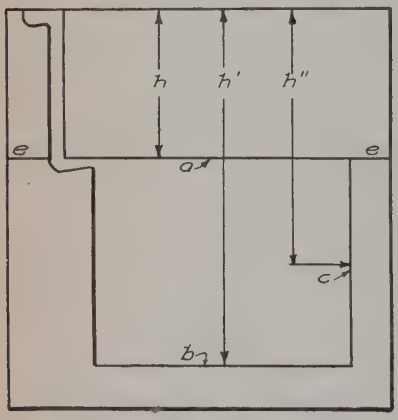


Fig. 29. Diagram Showing Analysis of Liquid Pressure

Now if we close the column *cd* at *d*, as in *C*, it is clear that it would require the actual weight of that column to balance the lifting pressure of the surface *d*, or $6\times.26\times1=1.56$ pounds. And if the larger area *df* is closed over, as in *D*, it takes 5 times this weight to resist the pressure exerted upon it by the runner, or $6\times.26\times5=7.8$ pounds. If the pattern projected 2 inches into the cope, the height of the runner above the surface acting against the cope would be 4 inches, and the pressure to be overcome would be equal to the weight of *cghe*, or $4\times.26\times5=5.2$ pounds.

The important factors, then, are: height of runner; and area of mold which presses against the cope. We can therefore state a rule: *To calculate the upward pressure of molten iron, multiply the depth in inches by the weight of one cubic inch of iron (.26), and multiply this product by the area in square inches upon which the pressure acts.*

Pressure-Distribution Example. Applying the second law cited, the strains on sides and bottom of molds and upon cores is explained.

By the rule just stated we first find the pressure per square inch at any given level by multiplying the depth by .26, and it is obvious that this pressure increases, the lower in the mold a point is taken.

In Fig. 29, the pressure at *a* equals $h \times .26$. This also acts against the sides at *ee*. The pressure at *b* is $h' \times .26$, and is exerted sidewise and downward. The pressure at *c* is $h'' \times .26$. This point, being half way between the levels *a* and *b*, represents the average sidewise or lateral pressure on all of the sides.

If this mold, then, is 11 inches square and 9 inches deep, with the pouring basin 6 inches above the joint, we have the following conditions:

Area of *a*	= 121 sq. in.
Area of *b*	= 121 sq. in.
Area of *c* (one side)	= 99 sq. in.
Area of four sides	= 396 sq. in.
Height of h = 6 in.; pressure head	= 1.56 lb. per sq. in.
Height of h' = 15 in.; pressure head	= 3.90 lb. per sq. in.
Height of h'' = $10\frac{1}{2}$ in.; pressure head	= 2.73 lb. per sq. in.

Multiplying these together, we have the pressures on the various faces as follows:

Upward pressure on *a*	= 188.76 lb.
Total pressure on side *c*	= 270.27 lb.
Total pressure on four sides	= 1081.08 lb.
Total downward pressure on *b*	= 471.90 lb.

A study of these figures shows the necessity of well-made flasks and bottom boards, for these must resist a greater pressure even than that required to keep the cope from lifting. They also show clearly why the lower parts of the casting resist the pressure of the gases more and require firmer ramming then the upper portions.

Variation of Pressure Head. A difference in the way a pattern is molded may make a great difference in the weight required on the cope. Compare *A* and *B*, Fig. 30. Supposing this pattern is cylindrical in shape and with the dimensions as indicated, we would have the following basis:

Area of circle a = 113.10 sq. in.
Area of circle b = 78.54 sq. in.
Area of ring $c'c'$ (b subtracted from a) = 34.56 sq. in.

Then

Total lift on cope A is $8\times.26\times113.10$ = 235.24 lb.
The lift on cope B is $8\times.26\times34.56 = 71.88$
$+(8+5)\times.26\times78.54 = 265.46$
Total lift on B = 337.34 lb.

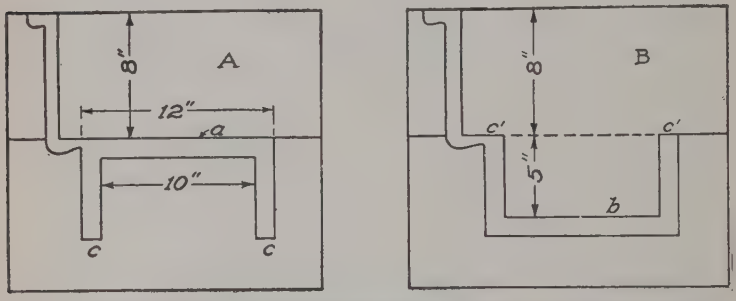


Fig. 30. Diagram Showing Difference in Pressure on Cope Due to Placing of Pattern

Variation of Pressure Distribution. Fig. 31 is an example of a core 5 inches square surrounded by 1 inch of metal, with a runner 6 inches high. We have here:

Pressure per square inch on a is
$7\times.26 = 1.82$ lb.

Pressure per square inch on b is
$12\times.26 = 3.12$ lb.

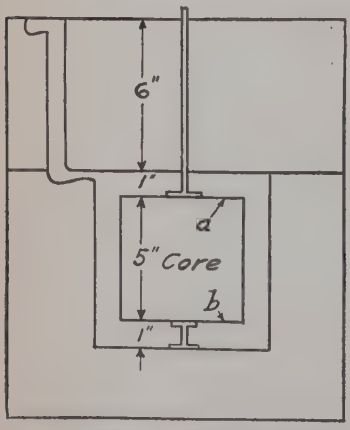


Fig. 31. Diagram Showing Difference in Pressure on Top and Bottom of a Cube

The difference in these pressures is 1.30 pounds per square inch. Then for every foot of length in the core we must balance a lifting pressure on the bottom of the core of $5\times12\times3.12 = 187.2$ pounds, until the metal covers surface a, when it will exert a counteracting downward pressure, and the strain on the chaplets will be only $5\times12\times1.30 = 78$ pounds.

Common Defects in Castings. Some of the ordinary defects which the beginner will find on his castings are as follows:

Short Pourings. The amount of metal in the ladle is misjudged with the result that the mold is not completely filled.

Blowholes. These come from gases becoming pocketed in the metal instead of passing off through the sand. This is due to hard ramming, wet sand, etc.

Cold-Shuts. These form when two streams of metal chill so much before they meet, that their surfaces will not fuse when forced against each other, as illustrated in Fig. 32.

Fig. 32. Cold-Shuts

Sand Holes. These come from the washing of loose sand or excess of facing into the mold cavity when pouring. They are usually bedded in the cope side of the casting.

Scabs. Scabs show like small warts or projections on the surface of the casting. They result from small patches of the mold face washing off. They may be caused from too much slicking, which draws the moisture to the surface of the mold, making the skin flake under the drying effect of the incoming metal.

Swells. Swells are bulged places on a casting and are due to soft ramming which leaves the walls of the mold too soft to withstand the pressure of the liquid metal.

Shrinkage Cracks. These are due to unequal cooling in the casting. They are sometimes caused by the mold being so firm that it resists the natural shrinkage of the iron, causing the metal to pull apart when only partially cold.

Warping. This occurs when these strains cause the casting to bend or twist, but are not sufficient to actually crack the metal.

TYPICAL MOLDING PROBLEMS

General Precautions. When starting to ram a flask, see that the sands to be used are well cut through and properly tempered. Select a flask large enough to hold the pattern and have at least 2 inches clear of the flask all around for bench work, and 4 to 8 inches on floor molds, depending upon the weight of the work to be cast. See that the flask is strong enough to carry the sand without racking

and that the pins fit. Have the necessary tools at hand, such as sieve, rammer, slicks, etc.

Jointing. Examine the pattern to be molded to see how it is drafted and note especially how the parting line runs. That part of the mold forming the surface between the parts of the flask is called the *joint,* and where it touches the pattern this joint must be made to correspond with the parting line.

The joint of a mold may be a plane or flat surface, or it may be an irregular one. When the joint is a flat surface it is formed entirely by the mold board except with work bedded in the floor; there it is struck off level with a straightedge. When it is irregular the drag joint must be *coped out* for every mold needed, that is, shaped freehand by the molder before making up the cope; or, by another method, the shape of the cope joint is built up first in a *match frame* with the cope part of the pattern bedded into it, and upon this form the drag may be packed repeatedly, receiving each time the desired joint surface without further work on the molder's part.

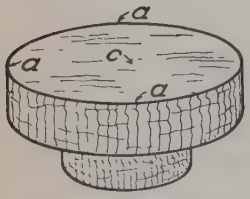


Fig. 33. Faceplate

Our first problems in molding illustrate these three methods of making the joint. It is aimed to give the directions for making up molds in as concise a form as possible. The student should refer frequently to the preceding sections and familiarize himself with the reasons underlying each operation.

Flat Joint. In the small faceplate shown in Fig. 33, all of the parting line *aaa* will touch the mold board, so the joint will be flat. The draft is all in one direction from the cope side *c,* therefore all of the pattern will be in the drag. Use a snap flask for this piece.

Molding Drag. Place a smooth mold board upon the bench or brackets. Place the drag with sockets down upon this. Set the pattern a little to one side of the center to allow for the runner. Sift sand over this about $1\frac{1}{2}$ inches deep. Tuck the sand firmly around the pattern and the edges of the flask as indicated by the arrows in Fig. 34, using the fingers of both hands and being careful not to shift the sand away from the pattern at one point when tucking at another.

Fill the drag level full with well-cut sand. With the peen end of the rammer slanted in the direction of the blows, ram first around the sides of the flask to ensure the sand hanging in well, as at *1* and *2* in Fig. 35. Next carefully direct the rammer around the pattern, as at *3*, *4*, and *5*. Do not strike closer than 1 inch to the pattern with the end of the rammer.

Shifting the rammer to a vertical position, ram back and forth across the flask in both directions, being especially careful not to strike the pattern nor to ram too hard immediately over it. The student must judge by feeling when this course is properly rammed. Now fill the drag heaping full of sand. Use the butt end of the rammer around the edges of the flask first, then work in toward the middle until the sand is packed smooth over the top. With a straightedge strike off the surplus sand to a level with the bottom of flask. Take a handful of sand and throw an even layer about $\frac{1}{4}$ inch deep over the bottom of the mold. On this loose sand press the bottom board, rubbing it slightly back and forth to make it set well. With a hand at each end, grip the board firmly to the drag and roll it over. Remove the mold board and slick over the joint surface with the trowel. Dust parting sand over this joint (burnt core sand is good on this work), but blow it carefully off of the exposed part of the pattern.

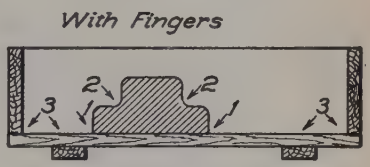


Fig. 34. Molding Sand with Fingers

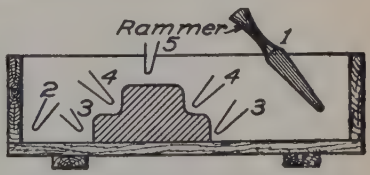


Fig. 35. Molding Sand with Rammer

Set the wooden runner or gate plug about 2 inches from the pattern, as shown in Fig. 23, page 24. In snap work the runner should come as near the middle of the mold as possible, to lessen the danger of breaking the sides, and to allow the weight to be placed squarely on top of the mold.

Molding Cope. Set the cope on the drag and see that the hinges come at the same corner.

Sift on a layer of sand about $1\frac{1}{2}$ inches deep. Tuck firmly with the fingers about the lower end of the runner and around

the edges of the flask. Fill the cope and proceed with the ramming the same as for the drag.

Strike off the surplus sand, swinging the striking stick around the runner so as to leave a fair flat surface of sand. Partially shape a pouring basin as illustrated in Fig. 23, with a gate cutter, before removing the runner. Draw the runner and finish the basin with a gate cutter and gently smooth it up with the fingers. Carefully moisten the edges with a swab and blow it out clean with the hand bellows.

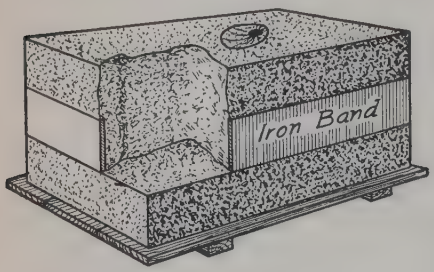


Fig. 36. Use of Iron Band

Lift the cope and repair any imperfections on the mold surface with the trowel or slicks. See that the sand is firm around the lower end of the runner. Blow through the runner and all over the joint to remove all loose parting sand. Slick over the sand which forms the top surface of the gate, between the runner and the mold.

Having finished the cope, moisten the sand about the edges of the pattern with a swab. Drive a draw spike into the center of the pattern and with a mallet or light iron rod, rap the draw spike slightly front and back and crosswise. Continuing a gentle tapping of the spike, pull the pattern from the sand. If any slight break occurs, repair it with bench lifter or other convenient slick. Cut the gate and smooth it down gently with the finger; blow the mold out clean with the bellows. No facing is needed if the castings are to be pickled. The mold should now be closed and the snap flask removed.

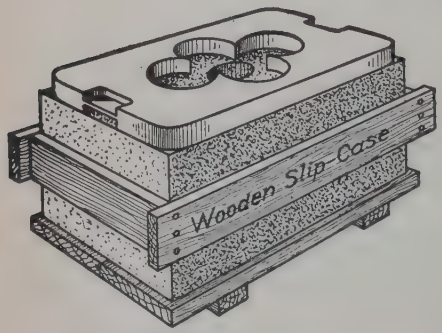


Fig. 37. Weight in Position

Strengthening against Pressure. There are two methods used to strengthen these molds against the casting pressure. One is

to use an iron band which will just slip inside of the flask before the mold is packed, as in Fig. 36. The other is to slide a wooden slip case over the mold after the snap flask is removed, as in Fig. 37. In either case the weight, shown in position in Fig. 37, should not be placed on the mold until pouring time, lest by its continued pressure it might crush the sand.

Coping Out. The second type of joint surface mentioned above is illustrated by the method of molding the tailstock clamp shown in Fig. 38. This is a solid pattern and rests firmly upon the mold board on the edges *aa*, but the parting line *bbb* runs below these edges. The bulk of the pattern drafts down from this line and so will be molded in the drag, while all above it will be shaped in the cope.

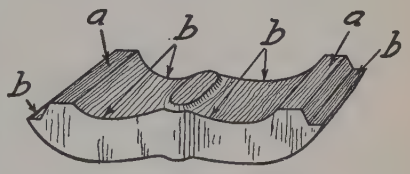


Fig. 38. Tailstock Joint

To mold the piece, set the pattern on the mold board, planning to gate into one end. Ram the drag, and roll it over, as described in the last example. With the blade of the trowel turned up edgewise, scrape away the sand to the depth of the parting line, bringing the bevel up to the main level of the joint, about $2\frac{1}{2}$ inches from the pattern, as shown at Fig. 39, and slick this surface smooth with the

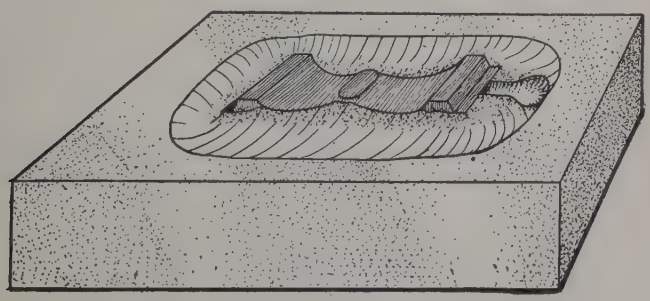


Fig. 39. Coped-Out Mold

finishing trowel or leaf and spoon. This process is called *coping out.* Dust parting sand on the joint thus made. Be careful not to get too much at the bottom of the coping next the pattern. Pack the cope, then lift it, and finish the mold as directed.

Shape of Draft. In coping out, the molder practically shapes the draft on the sand of the drag. Aim to have the lower edge of the coping parallel with the main joint for a short distance, and then spring gradually up to it at about the angle shown in the section at *c*, Fig. 40, as this is the strongest shape for the sand. If made with an abrupt angle as in *d*, the cope sand will tend to wedge into the cut with the danger of a drop or break when the cope is lifted.

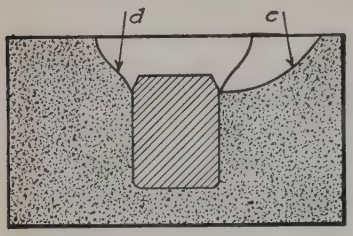


Fig. 40. Angle of Joint

In many cases, more especially in floor work, an abrupt coping angle may be avoided as follows: Set wooden strips, whose thickness is equal to the depth of the desired coping, under the edges of the drag when ramming up the pattern. (Use, for example, the hand wheel

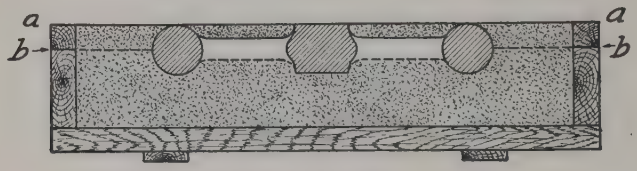


Fig. 41. Molding a Hand Wheel

shown in Pattern Making, Fig. 114.) When the drag is rolled over, the sand will be level with the top of strips and pattern at *aa*, Fig. 41. Remove the strips and strike surplus sand off level with edges of drag *bb*, and slick off the joint. Proceed with the cope in the usual manner. In gating this pattern, and wheels generally, place a small runner directly on the hub.

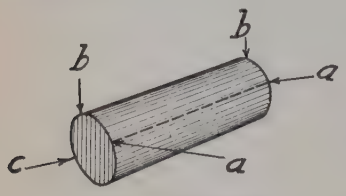


Fig. 42. Solid Bushing

Sand Match. The solid bushing, Fig. 42, serves to illustrate the use of a sand match. For exercise work, use only one pattern.

In practice, however, several small patterns are bedded into the same match. It is clear that in this pattern the parting line runs along the center of the cylinder, and to make a safe lift for the

cope it should follow around the circumference of the ends *abc*, as shown by the heavy lines.

The frame for the match is shallow, and of the same size as the snap flask with which it is used. It is provided with sockets to engage the pins of the flask. The bottom board is fastened on with screws.

Fill the match with sifted sand rammed hard. Strike off a flat joint and bed in the pattern. Cope out the ends to the lower edge of the pattern, as shown in Fig. 43, flaring it well in order to make a good lift. Slick the whole surface over smooth. Rap and lift the pattern to test the correctness of the work.

Replace the pattern. Dust on parting sand and ram the drag, tucking carefully in the pocket at each end. Roll the two over. Lift off the match, and set it to one side. The pattern remains

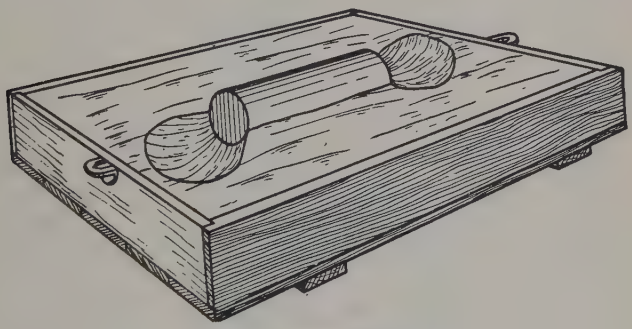


Fig. 43. Use of Sand Match

in the drag. Dust on parting sand. Set the runner and ram the cope as described. When the mold is opened and the pattern is drawn, it should be set back immediately into the match, ready for use again.

Usage. On account of economy of construction in the pattern shop, irregularly shaped work is often made in one piece. The molder must then decide whether it is cheaper to cope out each joint or to make up a sand match. Where the number of castings required is small, or where the pattern is large, it is better to cope out. But where a number of castings is required it is cheaper to make up a sand match. For methods of making quantities of castings and the use of a more permanent match, see the section on Duplicating Castings.

In the foregoing the main use of the match was to save time. It frequently happens that a pattern is so irregular in shape that it will not lie flat on the board in any position. In this case, a match is absolutely necessary before the drag can be packed. For large patterns, the cope box of the flask is used to bed the pattern into instead of a separate frame. After the drag has been packed upon it and rolled over, this first cope is dumped, and the box repacked

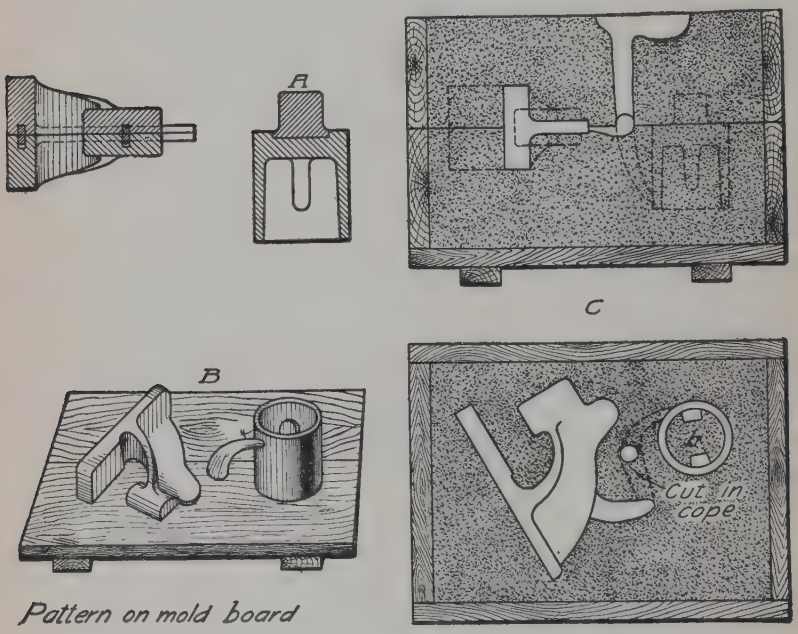


Fig. 44. Split- and Loose-Piece Patterns

with the necessary gaggers, vents, runners, etc., required for casting. The first cope is then termed, not a match, but a *false cope*.

For very light wooden patterns which may or may not have irregular parting lines, the pattern-maker builds up wooden forms to support the thin wood while the drag is being packed and to give the proper joint surface to the sand. This board serves exactly the same purpose as the sand match and false cope, but it is termed a *follow board*. See article on Pattern-Making.

Split-Pattern Molds. So far the patterns used have been made in one piece, but a flat joint is the most economical for the molder,

when many castings are required. Generally such pieces as bushings, pipe connections, and symmetrical machine parts are made in halves; one piece of the pattern remaining in each part of the flask when the mold is separated. There are many cases, too, where, to make a flat joint for the mold, the pattern maker can separate one or more projections so as to have the main part of the pattern in the drag and to let these loose parts lift off in the cope.

The small punch frame and the gas-engine piston, shown in Fig. 44, are examples of these two classes of patterns. At *A*, the sections through the patterns show the methods of matching them together. *B* shows the drag parts of the patterns in position for molding. At *C*, is the section through the mold and the plan of the drag showing how the gates are connected. Attention is directed to the use of the horn sprue—the sprue pattern is shown at *a*—by which the metal enters the mold at the bottom. If the gate were cut at the joint surface, there would be danger of cutting the sand on top of the green-sand core *b* as the metal flowed in upon it.

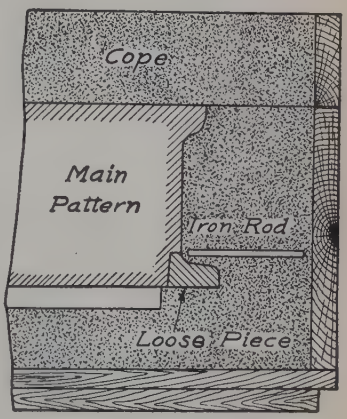


Fig. 45. Strengthening Mold with Iron Rod

Loose-Piece Mold. It often happens that bosses or projections are required on a casting at right angles to the main draft lines of the pattern and below the joint surface. Examples of such cases are shown in Pattern-Making. In molding such work, care must be taken that the overhanging portion of sand shall be strong enough to support itself. Where the projection is deep, the mold should be strengthened by nails or rods, as shown in Fig. 45. These should be wet with clay wash and set into the sand, when the mold is rammed.

Use of Green-Sand Core. Some work has projections on it which lie above or below the parting line in such a way that it cannot be molded by either of the foregoing methods. Examining the patterns for some of this work, we find two entire parting lines with the pattern made to separate between the two. Such patterns require between the drag and cope an intermediate body of sand,

from the top and bottom of which the two parts may be drawn. In small work, as illustrated by the groove pulley, this intermediate form is held in place by the sand joint of the cope and drag, and is termed a *green-sand core.* The method of molding

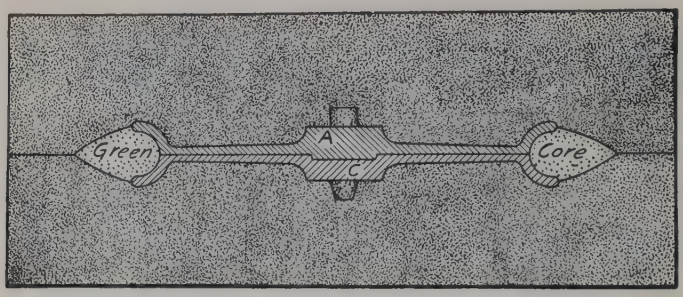


Fig. 46. Section of Mold

such a piece is given in Pattern-Making, Part I. To provide for pouring the casting, a runner should be placed on the hub of the first part packed *C*, Fig. 46, which shows a section of the mold before either part of the pattern has been removed. When the flask is rolled over to remove the final part *C* of the pattern, the runner is on top ready for pouring.

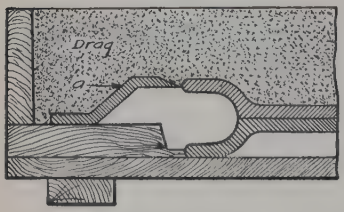


Fig. 47. Part Section of Mold Showing Use of Core-Lifting Ring

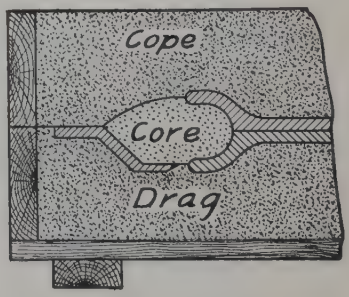


Fig. 48. Pattern Shown in Fig. 47 with Mold Complete

Core-Lifting Ring. Another method used does away with rolling the entire flask. A core-lifting ring is first cast slightly larger in diameter than the flange of the sheave, and having such a section as shown in *a*, Fig. 47. The ring is set in position in the middle of the inverted drag, the pattern is held central inside of the ring by the recess in the mold board. Pack the drag, roll over, and remove the mold board. Tuck the green core all around and

slick off the top joint of the core. Pack the cope in the usual way, lift it off, and draw the cope pattern. Now, by means of lugs cast on this lifting ring, the green core may be lifted off of the drag pattern, allowing it to be removed. Replace the ring and close the cope; and the mold is complete, as shown in section, Fig. 48.

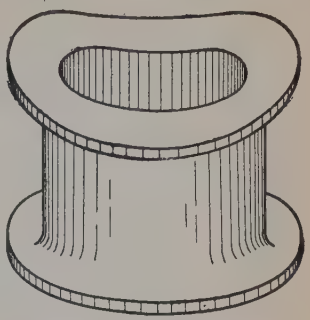


Fig. 49. Casting for Ten-Inch Nozzle

Three-Part Mold. In larger work, where the parting planes are farther apart, this intermediate body of sand is carried in a cheek part of the flask, and we speak of it as *three-part work.*

Fig. 49 shows a casting for a 10-inch nozzle, the mold for which illustrates this class of work. Here the pattern is separated just above the fillet of the curved flange. Fig. 50 gives a view of the mold, showing the way the joint is formed.

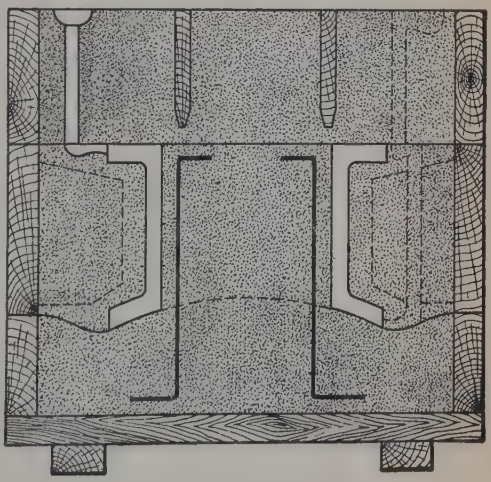


Fig. 50. Casting of a Nozzle

This casting should be made on the floor. Select a square flask, 4 inches on a side larger than the diameter of the flanges. The cheek should be as high as that part of the pattern which is molded in it. There should be two projecting bars on opposite sides of the cheek to support the sand, and crossbars in both drag and cope. These should be well wet with clay wash before using the boxes.

Set the pattern centrally inside the cheek, and place a runner stick just the height of the pattern in one corner of this box. On account of the depth of the cheek, the sand must be rammed in two courses. Sift enough facing sand into the box to cover the joint and 5 inches up around the pattern to a depth of about $1\frac{1}{4}$

inches, tucking about the pattern with the fingers. Fill in about 5 inches of loose sand and before ramming tuck around the ends of the side bars, compressing the sand between the finger tips, having a hand on each side of the bar, as illustrated in Fig. 51. Now use the peen end of the floor rammer in the same general way as the hand rammer is used in bench molding. Guide the rammer around the sides of the flask and bars first, then direct it toward the bottom edges of the pattern. As the sand gradually feels properly packed at this level, direct the blows higher and higher up. Proceed in this way to within about 1 inch of the drag joint. Make this joint by ramming in sifted facing sand, being careful to tuck it firmly underneath the flange. Cope this joint to the shape of the curved flange.

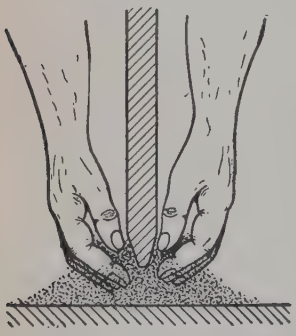


Fig. 51. Tucking Sand under Bars

Dust on parting sand. Place the drag in position and ram it up in the usual way, only using facing sand next the joint and pattern. Place six long gaggers to strengthen the sand which forms the inside of the casting. Clamp the drag to the cheek and roll them over. Test, repair, and dust parting sand on the joint. Try the cope. The bars should clear the pattern and joint by about 1 inch. Set the cope runner about 2 inches to one side of the cheek runner and set the riser in the corner opposite. Sift on facing sand and tuck well with the fingers under the crossbars. Shovel in well-cut sand and finish packing the cope. Form a pouring basin, and vent well. Lift the cope. Draw the pattern from the cheek. Join the runners on the cope joint and connect the mold with the riser. Lift the cheek and repair it. Draw the drag pattern. All of the mold surfaces should have black lead facing brushed over them with a camel's hair brush, and this facing slicked over. Cut a gate on the drag joint. Close the cheek on the drag. Close the cope on the cheek, and the mold is ready for clamping.

Floor Bedding. Owing to the development of the electric crane, there is much large work now rammed in iron flasks and rolled over, which was formerly always bedded in the floor. This method is still much used in jobbing shops to avoid making a complete large flask.

The mold shown in Fig. 52 illustrates the principal operations involved. The casting is a flask section for a special steel-ingot mold, and in design is simply a heavy plate braced on one side by flanges and ribs of equal thickness. For convenience in ramming between

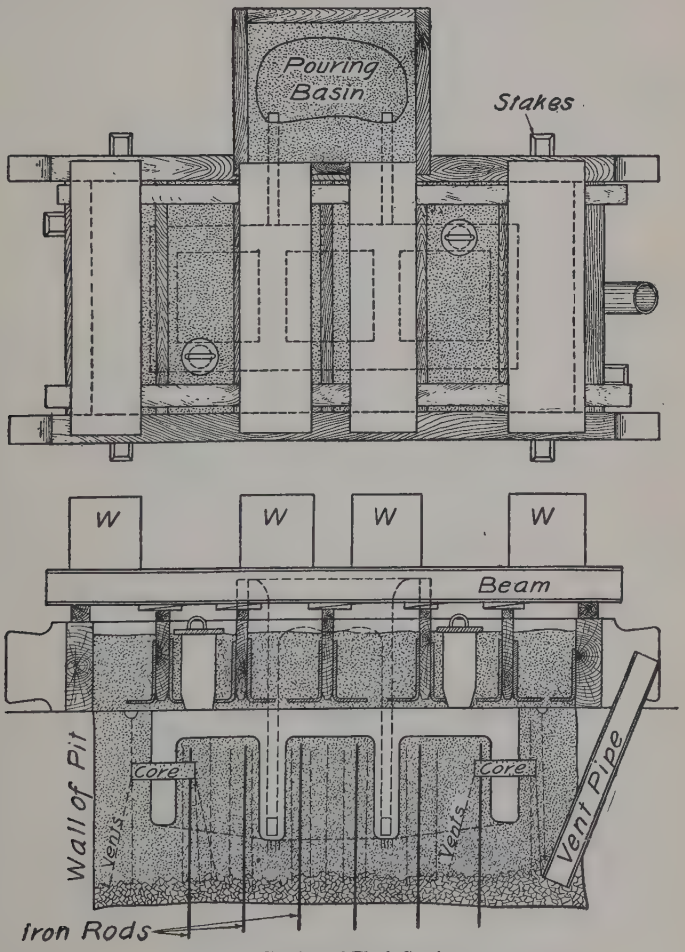


Fig. 52. Casting of Flask Section

the flanges, portions of the top plate of the pattern are left loose, as seen in Fig. 53.

Pit. Dig the pit for the mold 10 inches larger on each side than the pattern, and about 6 inches deeper. Having screened some hard cinders through a No. 2 riddle, cover the bottom of the

pit with them to a depth of 3 inches. Ram these over with a butt rammer, and at one end set a piece of large gas pipe. Put a piece of waste on the top of this to prevent its getting choked with sand. Ram a 3-inch course of sand over the cinder bed and strike it off level at the depth of the pattern from the floor line. Sift facing sand over this where the pattern will rest; set the pattern, and with a sledge, seat it until it rests level. Remove the pattern and with the fingers test the firmness of packing all over the mold.

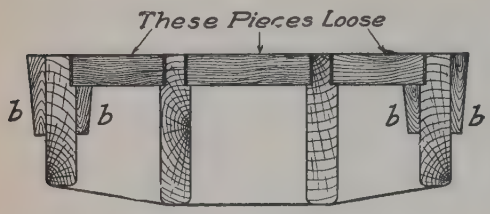


Fig. 53. Bedded-In Work

Vent these faces through to the cinder bed, and cover the vent holes with a $\frac{1}{2}$-inch course of facing sand. Now replace the pattern, and bed it home by a few more blows of the sledge. The top of the pattern should now be level and flush with the floor line. Seat the runner sticks, and, to prevent the sand on the bottom of the runners from cutting, drive 10-penny nails about $\frac{3}{4}$ inch apart into this surface until the heads are flush. Ram the outside of the mold the same as if in a flask, and strike a joint on top. Ram green sand between the inside webs of the pattern, and strike off at the proper height with a short stick *a*, Fig. 54. Drive long rods 3 inches apart into these piers to pass through to solid sand below the cinder bed.

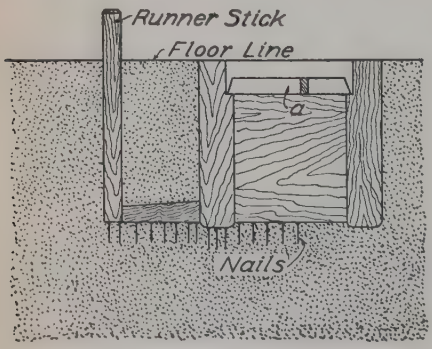


Fig. 54. Section Showing Method of Molding

Vent all around the pattern, outside and inside, through to the cinder bed. On top of the inside piers cover these vent holes with facing sand, ram, and slick to finish; then cover with the loose pieces of the pattern.

Cope. Try the cope and stake it in place; set the risers and vent the plugs. Ram the cope, slicking off level for about 2 inches around the top of the risers, to receive a small iron cover.

Lift the cope, repair, and face with graphite. Draw the pattern with the crane and finish the mold. Connect the outer vent holes by a channel with the vent plug. From the end of each core print *bbbb*, Fig. 53, vent through to the cinder bed, and set the cores. Close the cope. Set the runner box against the side of the cope and build a pouring basin with its bottom level with the top of the risers.

In weighting, great care must be exercised not to strain the cope. Place blocking upon the top ends of cope. Across these lay iron beams which will be stiff enough to support the load, and pile weights

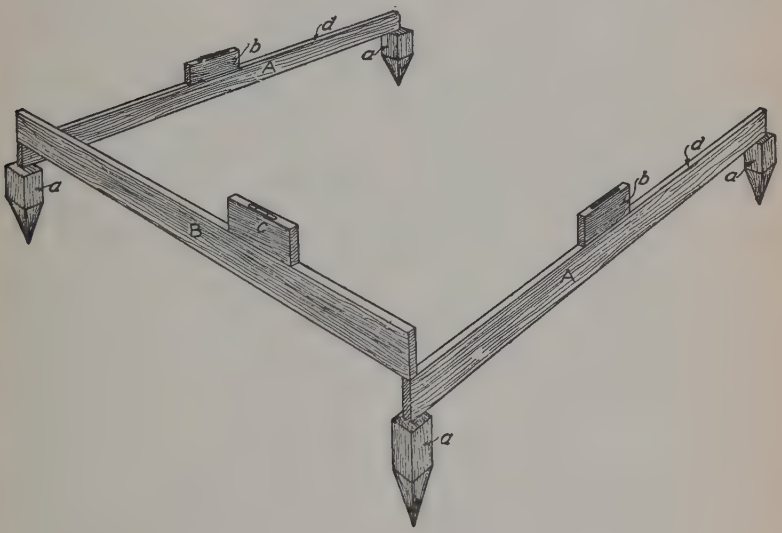


Fig. 55. Leveling a Bed for Open Sand Work

on these, as shown in Fig. 52. Now wedge under the beams to the crossbars of the cope at necessary points.

Open Mold. There is a large class of foundry rigging, such as loam plates, crossbars, and sides to iron flasks, which may be cast in open molds. As there is no head of metal, the beds must be rammed only hard enough to support the actual weight of the metal, or it will boil. To insure uniform thickness in the casting, the bed must be absolutely level.

Drive four stakes *aaaa*, as shown in Fig. 55, and rest the guide boards *AA* on the top of these. By using a spirit level *bb*, make

these level, and bring them to the same height by testing with the straightedge *B*.

The space between the guide boards *AA* should be filled with well-cut sand even with their tops *dd*. Sift sand over the entire surface. Strike this sand off $\frac{3}{8}$ inch higher than the guides, by placing a gagger under each end of the straightedge, as it is drawn over them. Tamp this extra sand to a level with the guides by rapping it down with the edge of the cross-straightedge, and the bed will be as shown in Fig. 56. We can now proceed to build up

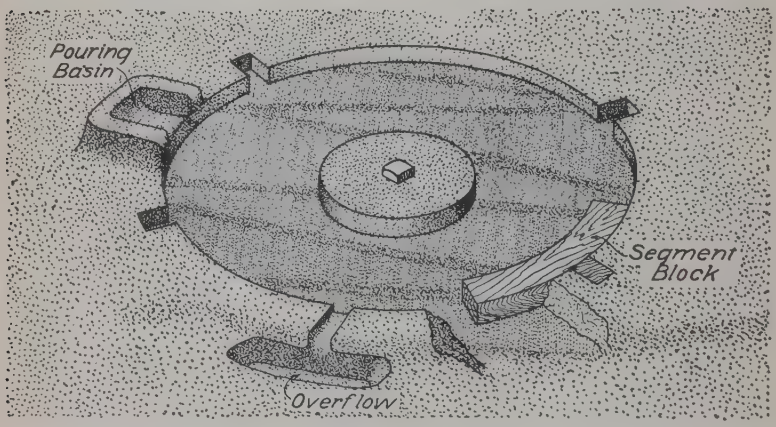


Fig. 56. Open Sand Mold

to a segment of pattern, or with a sledge drive a pattern into this surface.

The pouring basin should drain itself at the level of the top of mold, and an overflow may be cut on one edge to drain the casting to any desired thickness.

CORE WORK

Reference has been made in the first part of this article, under Divisions of Iron Molding, to the general difference between core work and green-sand work. This, and the section on Sands, the reader should review carefully.

Dry-Sand Cores

Materials. *Sand.* Here, as in green-sand molding, the principal material used is a refractory sand. In molding sand, however,

the alumina or clay forms a natural bond in the sand. To meet the necessary requirements of cores we must use a naturally free sand as a base, and give it bond by adding some form of organic matter as a binder, then bake the core.

Binders. The most common binders are the following four materials: Ordinary *wheat flour* is an almost universal material for use as a core binder. Every one is familiar with its action when moistened and baked. The hard vegetable gum *rosin*—a by-product of the manufacture of turpentine—for use as a core binder, should be reduced to a powder. It melts under the heat of the oven, flows between the grains of sand, and upon cooling binds them firmly together. *Linseed oil,* made from flaxseed, acts in a way similar to rosin; a small proportion of oil together with some flour makes a very strong core. *Glue,* which is obtained from animal hoofs and from fish stock, is also used to some extent as a core binder. It should be dissolved in water before mixing with the sand.

Tempering. A weak *molasses water* is used for tempering the sand for small cores; and on the larger work the same purpose is served by *clay wash.* There are many patent combinations of the above or similar materials put on the market as *core compounds.* There are two classes of these: dry compounds, and liquid compounds. The advantages claimed for them is that they are more economical—(1) because a smaller proportion of the compounds is sufficient to obtain the desired results; and (2) because a large proportion of the sand may be used over and over again.

Reinforcement. Among other necessary core-room supplies are: annealed *iron wire* No. 6 to No. 16, and round *bar iron* in sizes $\frac{1}{4}$-inch, $\frac{3}{8}$-inch, $\frac{1}{2}$-inch, $\frac{5}{8}$-inch, and $\frac{3}{4}$-inch, which are cut to length as needed, and are bedded in the core sand to strengthen the core, as will be demonstrated later.

Venting. A supply of clean *cinders* must be available also for venting larger cores. Small *wax tapers* make good vents for crooked cores. There is also a *patented wax vent* for sale on the market.

Facing. As before stated, *charcoal* with some *graphite* is the principal facing material used on cores. It is always applied in liquid form by dipping the core or by using a flat brush having extra long bristles.

Equipment. *General Tools.* The general tools of the core room are similar to those already mentioned. A piece of iron rod very often replaces the regular rammer on account of the small size of the opening into which sand must be packed.

The trowel is the most common slick, because most of the surfaces which require slicking are flat ones formed by striking off after packing the box. Except in the largest work, the entire face of the core is not slicked over, so a variety small slicks is not needed.

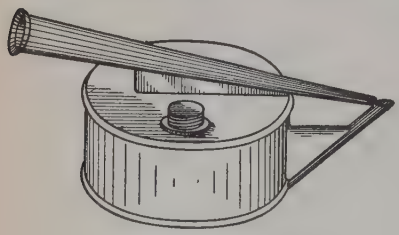


Fig. 57. Spraying Can

A spraying can, shown in Fig. 57, is used for spraying molasses water over small cores. Fill the can two-thirds full and blow into the mouthpiece.

Small cores are made up on a flat bench, the sand being in a small pile at the back. Larger boxes are rammed up on horses or on the floor, as is most convenient.

Baking. After being made up, cores are baked on core plates. The smaller plates are cast perfectly flat. Plates over 18 inches long are strengthened by ribs cast about 1 inch from the edge, as shown in Fig. 58; this keeps the plate from warping, and admits of its being picked up readily from a flat bench top or shelf.

Ovens are built with reference to the size of the cores to be baked. A good type of small oven is illustrated in Fig. 59. It can be run very economically with either coal or coke, and bakes cores up to 2 inches in diameter within half an hour. Each shelf is fastened to its own door, and, when open for receiving or removing cores, a door at the back of the shelf closes the opening. This prevents a waste of heat.

Fig. 58. Core Plate

Fig. 60 shows the section through an oven suitable for the largest work, including dry-sand and loam molds. The fire box *A* is situated in one corner at the back; its whole top opens into the oven. At the floor level diagonally opposite is the flue *B* for conducting the

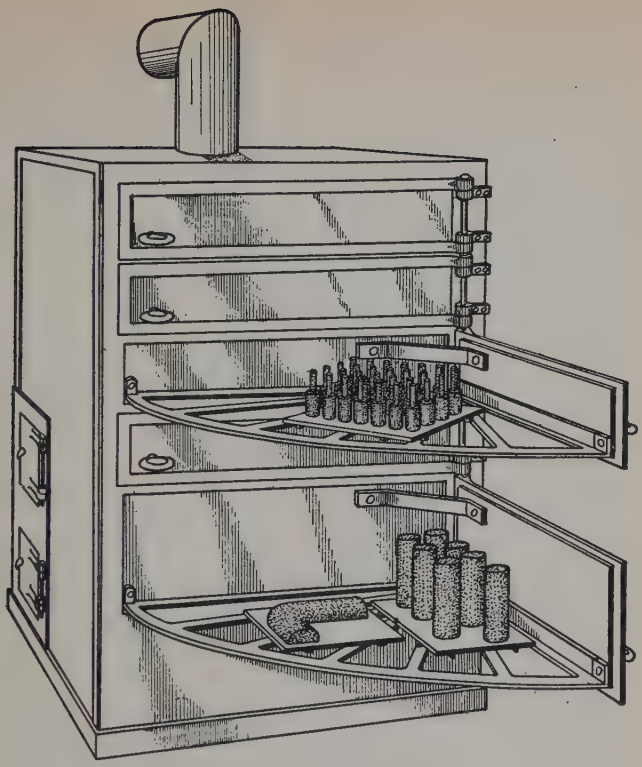


Fig. 59. Small Core Oven

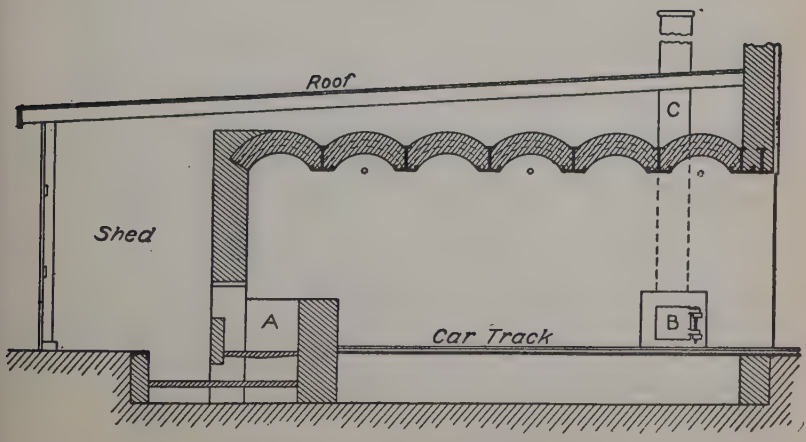


Fig. 60. Core Oven for Large Work

waste heat to the stack *C*. The entire front of the oven may be opened by raising the sheet-steel door. Two tracks side by side

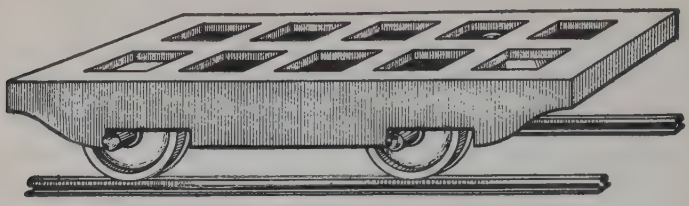


Fig. 61. Cast-Iron Car

accommodate cars upon which heavy work is run into the oven. Fig. 61 shows a good form of cast-iron car. The wheels are designed on the roller principle to make it easier to start the car when heavily loaded.

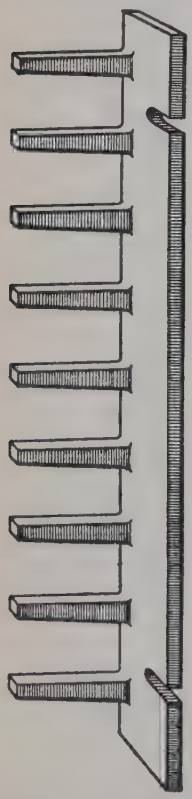


Fig. 62. Rack

For medium work smaller ovens of this type are used. Racks similar to the one shown in Fig. 62 may be bolted on the sides, arranged to hold the ends of the core plates; and the car may carry a line of double racks to increase the capacity of the oven.

Conditions of Use. As mentioned before, cores form those parts of a mold which are to be nearly or entirely surrounded by metal; in other words, such parts as would be in danger of breaking or require too much work to be constructed in green sand. The object, then, in making cores is to insure a better casting and to reduce costs.

Cores are held in position by means of core prints (see Pattern-Making). The main weight of the core is supported by these prints and through them all vent must be taken off and all sand removed in cleaning. Therefore, cores must be stronger than green sand, because, whether large or small, they must stand handling while being set and must not cut or break during pouring. They require greater porosity than green sand because their vent area is limited and their composition contains more gas forming material. Furthermore, cores must lose all their

bond by the time the casting is cold, so that the sand may be easily removed no matter how small the available opening.

These conditions are obtained by using a coarse free sand and a binder. To give additional strength when necessary, iron wire or rods, or cast-iron core arbors are bedded in the core. These serve the same purpose in a core that the flask does in green-sand work.

Binder. The action of the binder enables the sand to retain its shape when the box is removed, and renders the core hard and strong when baked. In the mold the intense heat of the metal gradually burns out the organic matter or binder, leaving the core without bond. In this condition, the sand may readily be removed.

Too much binder tends to make the core sag out of shape before baking, and blow when metal strikes it; that is, give off more gas than the vents can carry away. With too little binder the sand does not bake hard, and cuts when the mold is poured.

The effectiveness of all binders, especially flour, depends upon their thorough mixing with the sand. The especial value of rosin and oil lies in the fact that by melting under the oven heat they form a more perfect bond with the sand.

Many intricate cores are now made with an oil mixture, without using rods or wires, which formerly were considered absolutely necessary for strength. Such cores must be well supported when green, must be thoroughly baked, and handled with much care until they are cold.

Core-Sand Mixture. No universal mixture for core sand can be given, as sands vary so much in different localities. The mixtures, as shown on the following page, illustrate approximate proportions.

In preparing core sand, the different ingredients should be measured out, thoroughly mixed, and sifted while dry. Temper the mixture a little damper than molding sand. Too much moisture makes the sand stick to the box. Not enough makes it hard to work and gives a crumbly surface if dried.

Facing. Blacking for light work should include one cup of molasses to a pail of water, into which is worked powdered charcoal until an even black coating is deposited upon the finger when dipped into the blacking and out again.

Core Mixtures

Materials	Small Cores (parts)	Large Cores (parts)	Intricate Smaller Cores (parts)	
Beach sand	10		15	15
Fire sand			15	
Molding sand				5
Sharp fire sand		8		
Strong loamy sand		2		
Flour	1	1½	1	2
Rosin			2	
Oil				1
Tempering means	Molasses water	Clay wash	Molasses water	

For heavy blacking there should be used about 2 parts charcoal and 1 graphite, mixed into thick clay wash.

Miscellaneous. In finishing small cores, they should be sprayed with weak molasses water while green, then well baked and removed from the oven. When cool enough to handle, they are dipped into the blacking; then put back in the oven until this facing has dried. For large cores the blacking is applied with a brush before baking.

All cores should be baked as soon as made, for air-drying causes the surface to crumble.

Cores must not be set in a mold while they are hot, or the mold will sweat, that is, beads of moisture will form on the inside faces. This would make the mold blow when poured.

A core should be rammed evenly and somewhat harder than a mold. Too hard ramming will make the sand stick in the box, besides giving trouble in casting. Too light ramming makes a weak core.

From the very nature of cores, the matter of venting them is very important and often calls for much ingenuity on the part of the core maker.

For simple straight work a good sized vent wire is run through before the box is removed. Half cores have their vents cut in each half before pasting together. Cinders are rammed in the center of large cores connecting through the prints, with the mold vents. For crooked cores, wax vents are rammed in the center—the wax melts away into the sand when the cores are baked, leaving smooth even holes. This is illustrated in one of the following examples.

Methods of Making. The examples here given serve to illustrate the principal methods used in making cores.

Small Cylindrical Core. The simplest form of core is one which can be rammed up and baked as made by simply removing the box. Short bolt-hole cores, etc., are made in this way, as shown in Fig. 63.

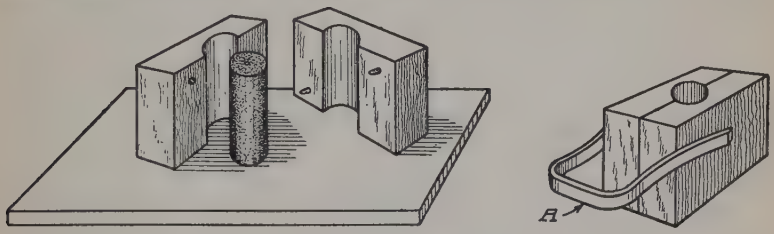


Fig. 63. Short Bolt-Hole Cores

Set the box on a flat bench top. Hold the two halves together by the clamp *A*. Ram the hole full of core sand by the use of a small rod. Slick off the top; run a good sized vent wire through the middle of the core. Remove the clamp. Set the box onto the core plate, rap the sides, and carefully draw them back from the core.

Symmetrical Shapes. Larger cylindrical cores, up to about $1\frac{1}{2}$ inches diameter, are rammed in a complete box also, only they are rolled out on their sides, as shown in Fig. 64. This, however, tends to make a flat place on the side, from the weight of the sand supported on this narrow surface.

For this reason cylindrical cores of large diameter, and many symmetrical shapes, are made in half boxes. See Pattern-Making, Figs. 110, 208, 213, and 219. Such boxes are rammed from the open side. Wires are bedded when necessary about in the middle of the half core. The fingers and the handle of a trowel are often used to ram the sand, and with the blade of the trowel the sand is struck off and slicked to the level of the top of the box.

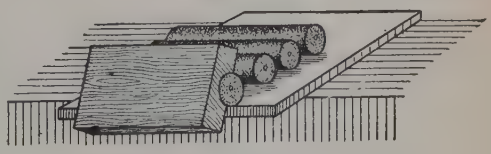


Fig. 64. Large Cylindrical Cores

When baked, two half cores are held with their flat sides together, and any slight unevenness in the joint removed by a gentle rubbing

motion. A vent channel is then scraped centrally on each half. Paste, made of flour and molasses water, is applied around the edges and the two halves pressed firmly together; care is taken to see that they register all around. The core should then be placed in the oven to dry out the paste. When pasting cores of 6-inch diameter and over, it is well to bind the halves at each end with a single wrap of small wire.

Proper Seating. Wherever possible, core boxes should be made with their widest opening exposed for packing the core, and designed so that the core may rest, while being baked, on the flat surface formed by striking off at this opening.

Core plates will sometimes become warped. When a core would be spoiled by resting it directly upon such a plate, the unevenness is

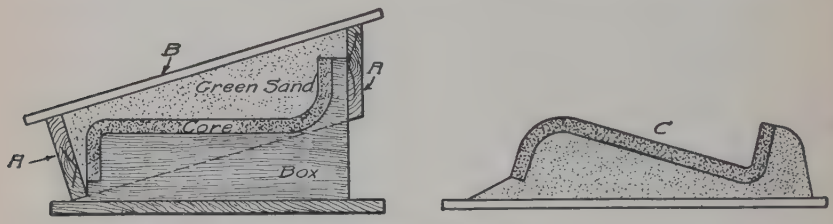


Fig. 65. Bedding a Crooked Core

overcome by sifting upon the plate a thin bed of molding sand and seating the core on this.

Crooked Shapes. All cores cannot be made with a flat surface for baking, as illustrated by a port core, the box for which is shown in Pattern-Making, Fig. 251. This core must be rolled over on a bed of sand. Using an oil mixture, ram the core carefully, bedding into it several wax vents. These should start near the end which will touch the main cylinder core and lead out of the end which will enter the chest core. To get this crooked core on a plate for baking, a wooden frame is roughly nailed together, which is large enough to slip over the core box when the loose pieces have been drawn off of the core, as shown in *A*, Fig. 65.

The space on top of the core is now filled with molding sand, rammed just enough to support the weight of the core. The edges of the frame project above the highest points of the core and form guides for striking off this sand and seating a core plate, as at *B*,

Fig. 65. Box, frame, and plate are now firmly clamped and rolled over, and the frame and box removed, leaving the core well bedded on the plate ready for the oven, as at *C*.

In manufacturing plants quantities of cores are often required which cannot be baked on a flat plate. To save the time and material necessary to roll each core onto a bed of sand, metal boxes are made, Pattern-Making, Figs. 233 and 234, and the core is baked in one part of the box. Only one casting is required of the larger portion of the box. The smaller part is duplicated for every core required for the day's mold.

Rod Reinforcing. Mention has been made of the use of wires for strengthening small cores. In making larger ones, there is a greater weight of sand to cause strain in handling the core, and proportionately greater casting strain. To resist these stresses a systematic network of rods is bedded in the core while being rammed, as shown in the sectional view, Fig. 66. Heavy bars *aabb* extend the length of the core to give the main stiffness. Smaller cross-rods rest on these at the bottom and top, and with the small vertical rods tie the whole core together.

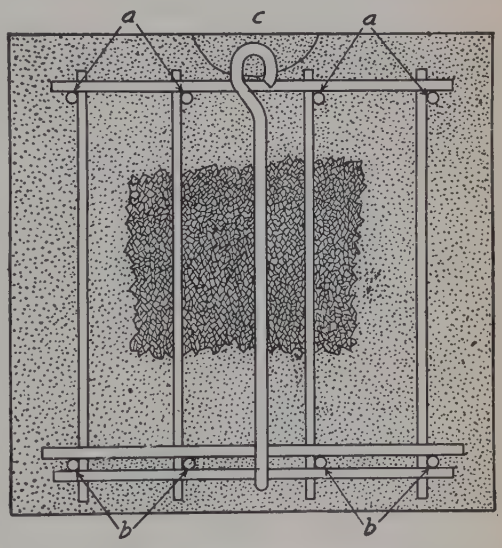


Fig. 66. Network of Rods in Cores

At even distances from each end lifting hooks *c* are placed. Cross-rods through the lower eyes of these hooks bring all the strain of the lift on the long heavy core rods. The holes in the top of the cores where the lifting hooks are exposed, are stopped off when the core is in the mold, by moistening the sides of the holes with oil and filling up with green sand.

Cinders are packed in the middles of such cores. They aid in drying the core. They furnish good vent, and they allow the sand

to give when the casting shrinks, thus relieving the strain on the metal itself.

Use of Arbors. For the largest class of cores for green-sand work, cast-iron core arbors are used, of which a very satisfactory type is shown in Fig. 67. This consists of a series of light rings, *A*, carried on a cast-iron beam, *B*. The rings are of about $\frac{1}{2}$-inch metal cast in open sand and set about 8 inches on centers, and may be wedged to the beam. The beam has a hole at each end for lifting the core.

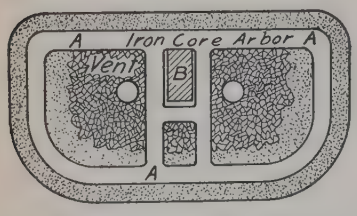


Fig. 67. Sections Showing Use of Cast-Iron Core Arbor

This skeleton is made up and tried in the box before the work of ramming the core is begun. It is then removed and given a coat of thick clay wash. A layer of core sand is first lightly rammed over the inside of the box, and the core arbor seated into this. The full thickness of core-sand facing is then firmly rammed, and the entire center filled with well-packed cinders. Vents through the facing at both ends provide for the escape of gases from these cinders.

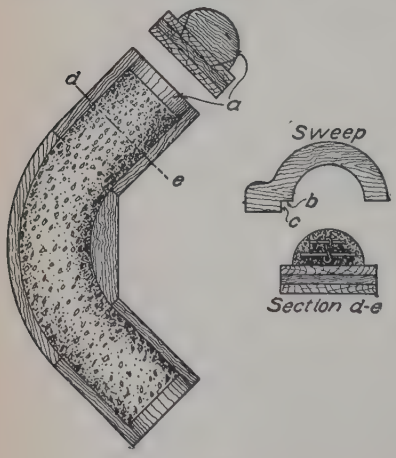


Fig. 68. Pipe Core

Sweeping. Often, when but one or two large cores are wanted, the cost of making a box is saved by sweeping up the core. This is illustrated in the pipe core shown in Fig. 68.

The pattern-maker gets out 2 core boards and 1 sweep. The boards are made by simply nailing together 3 thicknesses of $\frac{7}{8}$-inch stuff, with the grain of the middle piece crossing that of the others to prevent warping. The outer edges of the boards have the exact curve of the outside of the pipe pattern, and at the ends is tacked a half section of the core, shown at *aa*. One sweep does for both boards. The curve is cut the exact half section of the core. The edge *b* equals the

thickness of metal in the casting, and the stop *c* acts as a guide along the outer edge of the board.

In making up this core, a thin layer of core sand is spread on the board and the outline of the core swept. On this the rods with their lifting hooks are bedded, and the vent cinders are carefully laid along the middle. The whole general shape is then rammed up in core sand larger than required, and by using the sweep it is brought to exact size. The core is then slicked off, blackened, and baked while still on the board. When both halves are dried, they are pasted together, the same as with smaller work. To

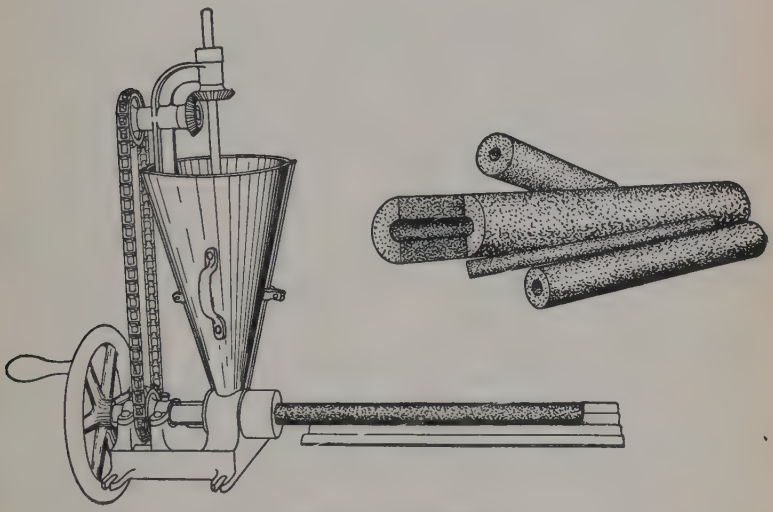


Fig. 69. Core Machine

prevent breaking the lower half when turning it over to paste, it is rolled over on a pile of heap sand.

Core Machines. For making stock cores, round or square, several styles of core machines have been put on the market within the last few years, of which the one illustrated in Fig. 69, is a good representative. This is arranged to be driven by hand or by power. The core sand is placed in the hopper, and by means of a horizontal worm at the bottom it is forced through a nozzle under just the right pressure to pack the core firmly. A clean-cut vent hole is left in the middle of each core. As the core is forced from the nozzle it is received on a corrugated sheet-steel plate, which is moved

along to the next groove when the core has run to the full length of the plate.

The advantage of the machine is that with it an apprentice boy can produce a true, smooth, perfectly vented core, in very much less time than could possibly be done by hand-ramming.

Setting Cores

Cylindrical Cores. *Plain Fitting.* Among the following examples showing typical ways of setting and securing cores in molds and of connecting vents, the bolt-hole core, shown at *A*, Fig. 70, illustrates the simplest form of core to set. Only a drag print is necessary; the flat top of the core should just touch the cope surface of the mold. The level may be tested by a straight stick or by

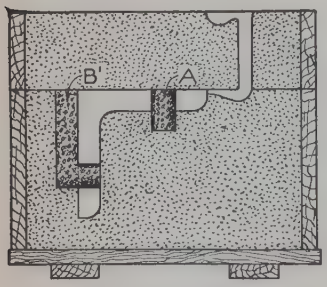


Fig. 70. Bolt-Hole Core

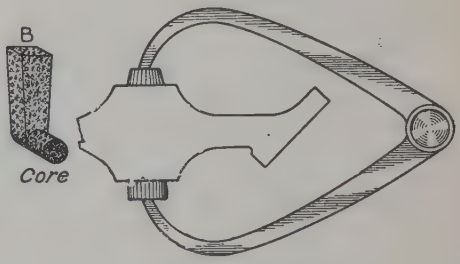


Fig. 71. Calipers

sighting across the joint. If the core is too long, one end may be filed off a little, if too short, a little sand may be filled into the bottom of the print. For longer cores, especially hub cores, a taper print is placed on the cope side of the pattern, and the same taper is given to the end of the core; this guides it to the exact center when the mold is closed. Numerous examples are shown in Pattern-Making. The exact length of the core should be obtained from the pattern with a pair of calipers, as shown in Fig. 71. One point of the calipers should then be placed on the taper end of the core, and the print filled in, or the core shortened in case of variation from the right length. It is well to make a vent hole from the center of each print before setting the core.

With pattern and core boxes properly made, little difficulty should be experienced in setting small horizontal cores for hollow bushings, pipe connections, etc. (See Pattern-Making, Figs. 110,

203, and 210.) The core must fit the print or a poor casting will result. The sand supporting the prints must be tucked firmly enough to withstand the lifting pressure on the core. A scratch

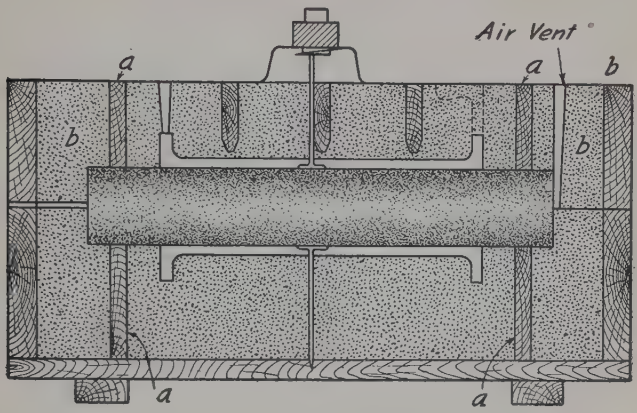


Fig. 72. Supported Body Core

with the point of the trowel along the joint surface from the end of the print to the edge of the flask, will usually take care of the vent.

For larger cores of this character crossbars made to fit snug against the core print are nailed in both drag and cope. See *aaaa*, Fig. 72. These hold the core absolutely firm. The spaces *bb* in the cope, are not packed until the core is set, when it is a simple

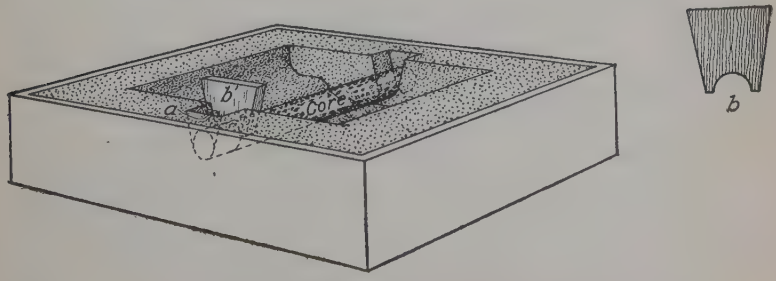


Fig. 73. Setting Core below Surface

matter to ram these spaces and take off an air vent directly from the center of the core.

Holes below Joint Level. There are two methods of coring holes below the level of the joint. One is shown clearly in Fig. 73.

A stock core is set in the bottom of the prints; a wooden template, shown at *b* and *b'*, is set over the core, and the print *a* is then packed with molding sand, or *stopped off*, as it is termed.

The other method is shown at *B* and *B'*, Fig. 70. Here that part of the core which will shape the hole through the casting, is formed on the end of a core which exactly fills the print. A single operation sets the core and stops off the print. For this reason this method is used where a large number of such holes are to be cored.

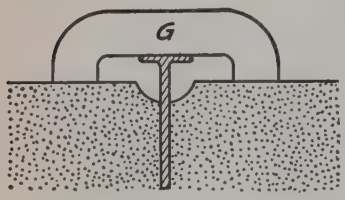


Fig. 74. Gage for Setting Chaplets

Setting Chaplets. In setting chaplets, the height of the lower one may be tested with a rule, with a straightedge rested on the prints, or by a gage similar to that shown in Fig. 74. A small boss is usually formed by pressing the trowel handle into the mold where the chaplet is to go.

The cope chaplet is not fastened until the mold is closed, then the stem can be properly wedged down under a bar clamped across the top of the mold.

Projecting Cores. *Balanced Type.* In work where a hole must project well into the casting, but not all the way through it, a balanced core is often used. Such a case is illustrated by the rammer head, Fig. 75. When making this core, let the vent extend through the entire length, then stop up the vent at the small end with a bit of clay after the core is baked.

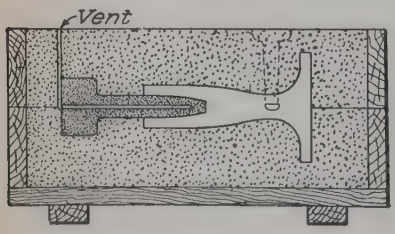


Fig. 75. Small Balanced Core

It is not always practicable to enlarge the print as shown here, but when possible, it reduces the length of print necessary to balance the projecting end and ensures accurate depth to the hole.

Heavy Form. Heavy projecting cores must be supported by chaplets, as illustrated in Fig. 76. Vents may be taken off through a channel and air riser as explained in the section on Venting. Fig. 77 shows the shape of the print on the pattern for this mold at *a*, the

pockets formed by the core are shown at *bb*, and *c* indicates the position of the gate.

Hanging Cores. A core is frequently used to avoid a deep lift for the cope. Suitable wire hangers, shown at *a*, Fig. 78, are bedded in the core when it is made. In setting the core, small annealed wire about No. 20 or

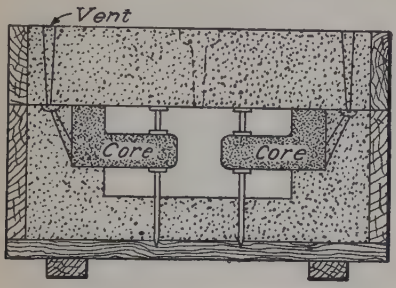


Fig. 76. Large Balanced Core

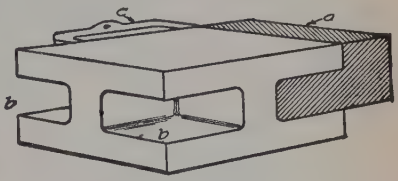


Fig. 77. Shape of Print on Pattern for Projecting Core

No. 24 gage is looped through the hangers, passed through small holes made in the cope, and fastened with a granny twist over an iron bar on top. This bar should bear on the sides of the cope and the core be brought up snug in its print by wedging under its ends. The rigging need only be strong enough to support the weight of the core, for the pressure of metal will force this core firmly into its print with little danger of shifting it. For heavy cores, a lifting eye, as previously illustrated in Fig. 66, takes the place of the wire hanger, and the core is hung by means of a hooked rod with a nut on the end. As shown in Fig. 79, this rod passes through a long washer which bears on a pair of rails, or similar stiff rigging.

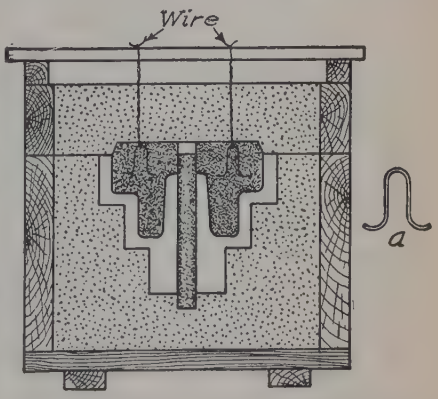


Fig. 78. Section Showing Use of Wire Hangers

Bottom-Anchored Cores. Where possible, the placing of cores in the bottom of molds should be avoided, for in this position, being much lighter than molten iron, they must be secured against a pressure tending to float or lift them. This pressure is proportionate to their depth below the pouring basin. But the metal

at the bottom of a mold is cleaner and more sound than that at the top. Therefore, planer beds, large faceplates, and pieces of this character are usually cast face downward, making it necessary to anchor the T-slot cores in the bottom of the mold.

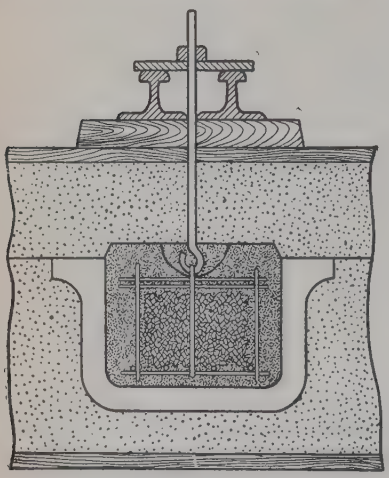


Fig. 79. Section Showing Use of Lifting Eye for Heavy Cores

In some cases, such cores may be held down by driving nails so that their heads project somewhat over the ends of the core, as shown in Fig. 80. If this method is not strong enough, pointed anchors, with a foot on one end, are run through a hole in the core, and are carefully driven into the bottom board, as shown in Fig. 81. Where the work is bedded into the floor, a plank must be set to receive these anchors just below the cinder bed. As in the case of lifting eyes, the holes in the core, into which the foot on the anchor is driven, are smeared with oil and stopped off with green sand.

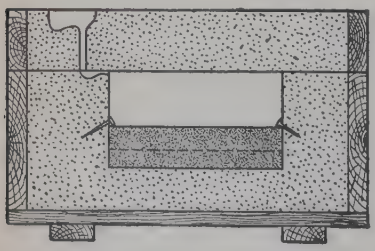


Fig. 80. Section Showing Use of Nails to Hold Cores in Place

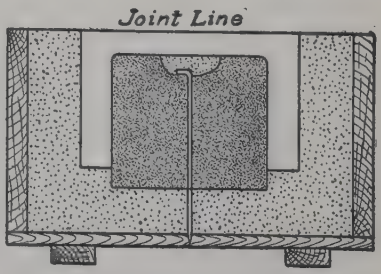


Fig. 81. Section Showing Use of Anchors to Hold Cores in Place

Green-Sand Cores

Expediency in Use. Many times the jobbing foundry may find it expedient, where patterns and core boxes are furnished by the customer, to make certain changes which will reduce the cost of production; for, unhappily, the patterns furnished sometimes

show a great desire on the part of the pattern-maker to produce the patterns cheaply, without making due allowance for difficulties encountered in the foundry.

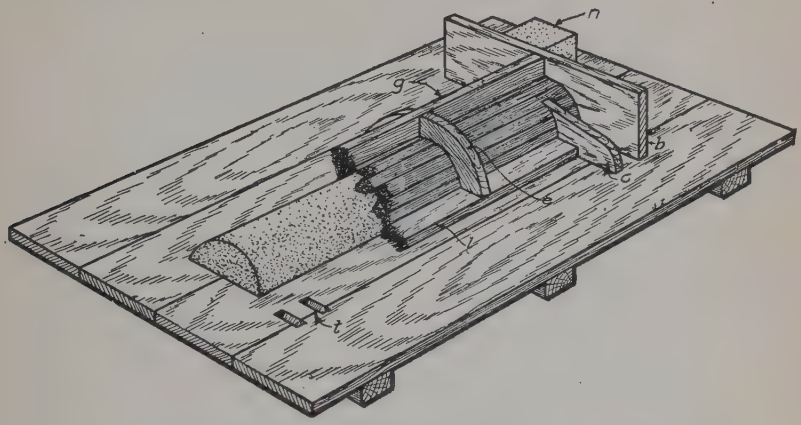


Fig. 82. Half Core with Box Built around It

Typical Instance. The practice of substituting green-sand cores for dry sand has many possibilities. As an example, consider the case of a flange and spigot pipe 72 inches long and 6 inches

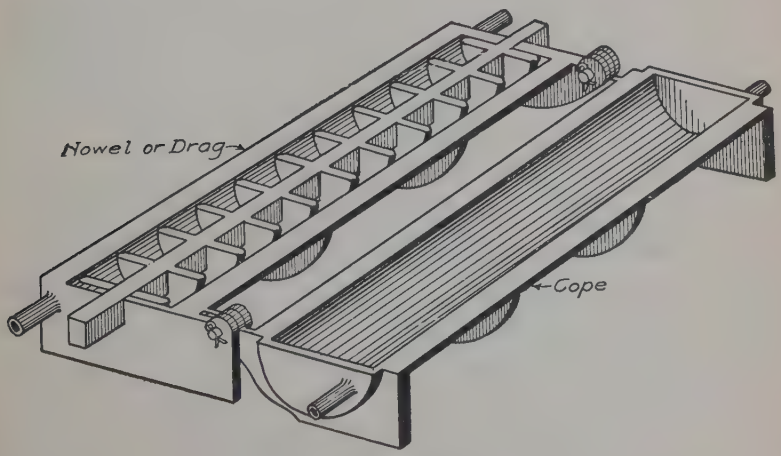


Fig. 83. Completed Mold for Core

inside diameter. The pattern furnished was satisfactory, as was the half-core box, until it was found that the number to be made each day was gradually increasing and the number of half cores

to be dried was seriously interfering with the production of the regular cores required. It was decided by the foundry management

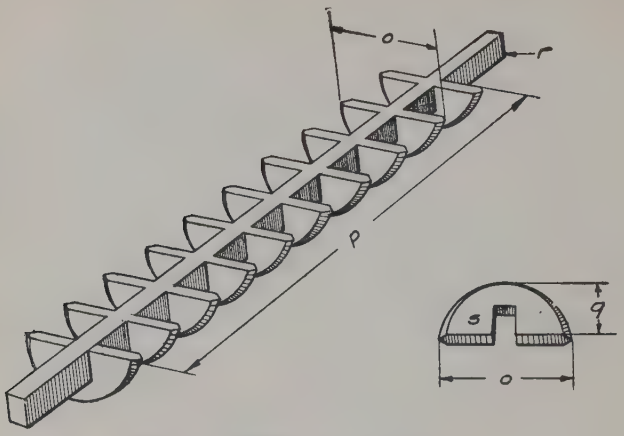


Fig. 84. Cast-Iron Arbor to Carry Core

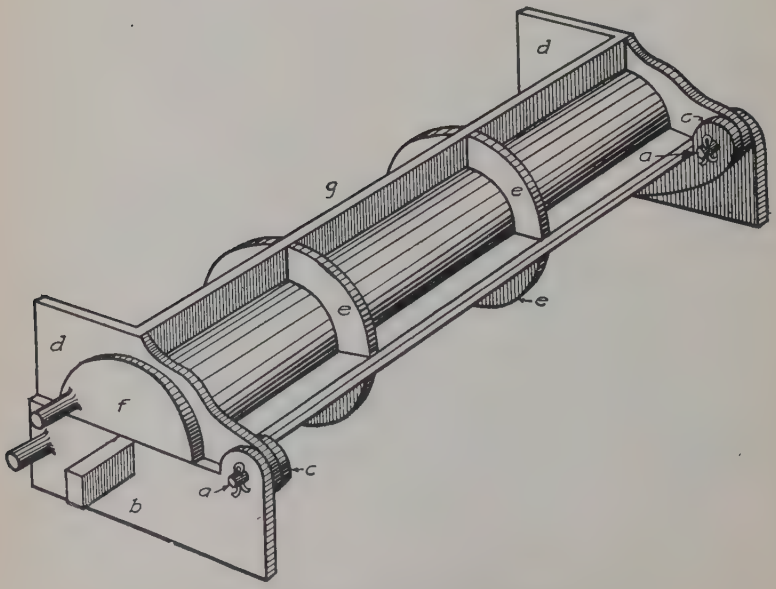


Fig. 85. Mold with Two Halves Together

to adopt the use of a green-sand core, and not only relieve the core ovens, but also effect a considerable saving in core sand and core

binders. To make a green-sand core it was necessary to make the core box. The method used was as follows:

First, a half core was made in the original box, and when this

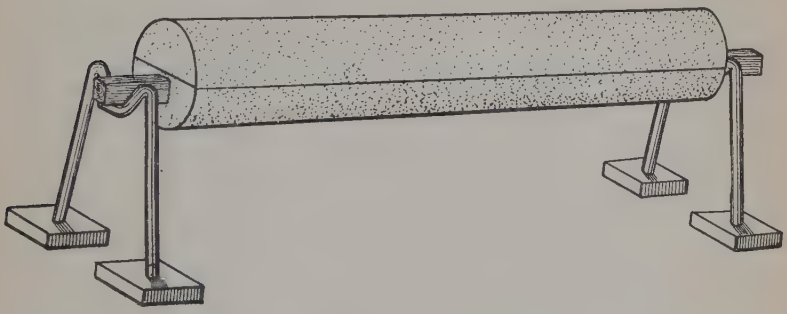


Fig. 86. Complete Core Placed on Horses

was dried it was placed on a new mold board as shown in Fig. 82. Over this was placed lagging of the desired thickness for the casting, as shown in the figure; then over this were placed the loose pieces

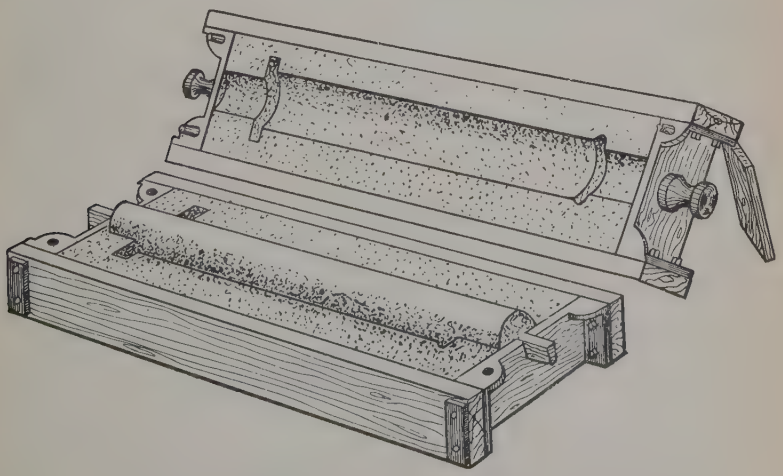


Fig. 87. Complete Mold with Green-Sand Core in Position

b to form the ends of the box and part of the hinge *c*, also forming a part of hinge on drag half of box, and *e* and *g* acting as strengthening ribs.

With these loose pieces in position the drag was duly rammed and rolled over, the cope was rammed and the dry-sand core secured in and lifted off with the cope. The loose pieces were withdrawn from the drag, and the mold was properly finished; when closed and poured, this gave a satisfactory casting of the drag half of the core box. The cope half was made in the same way, the only change being in the shape of the loose pieces forming the ends as seen in Fig. 83.

An arbor being required to carry the green sand, it was made of cast iron, as shown in Fig. 84. To make the green-sand core, first riddle sand in the drag half of the core box; next place the arbor as shown in Fig. 83; then fill and carefully tuck the sand under the flanges on the arbor. The cope is simply filled with sand and rammed, and both drag and cope are struck off level with the joint. The two halves are now closed, as shown in Fig. 85, when the cope may be rolled back to its former position and the core removed from the drag half of the box by lifting an arbor extending through the end of the box.

The core should be placed on horses as shown in Fig. 86, so that it may be repaired if necessary and blackened. Fig. 87 shows the complete mold with green-sand core in position.

In this way a satisfactory core box was made without heavy expense for patterns, as the foundry carpenter or flask man was able to produce the loose pieces from a rough sketch furnished by the foundry foreman.

DUPLICATING CASTINGS

Practical Requisites in Hand Molding. Devising methods for increasing production and decreasing its cost is one of the important problems of modern engineering in the foundry as well as elsewhere. In the jobbing foundry where there is a great variety not only in the patterns themselves, but in the number of castings called for from each pattern, the molder makes up a sand match as already described. On this match he arranges such an assortment of patterns as will fill his flask, and beds them into place. From a well-made sand match two or three hundred molds may be made up. When the desired number of castings is made from one pattern on the match, that one is removed and another one which fits in its place is substituted.

Gated Patterns. For manufacturing purposes thousands of the same casting may be required, calling for more durable patterns and match. Metal patterns are made and as many as can be cast in a flask are soldered to a smoothly finished metal gate pattern. With a draw screw inserted in this gate, all of the patterns may be drawn at once. Two steady pins should be screwed and sweated into the drag side of the gate pattern. These should be of small round brass rod and should project below the deepest point of the patterns, for they guide the pattern as it is being drawn and prevent it from swaying and breaking the edges just as it leaves the sand. Patterns so arranged are termed *gated patterns.*

Permanent Match. When such patterns have a flat joint, a special mold board should be provided, and the patterns stored on the same board. When the joint is irregular, a permanent oil match should be made. Make a strong hardwood frame the size of the flask and about 1 inch deep, with the bottom board arranged to screw on to the back. Nails should be driven into the inner sides hanging parallel to the bottom board. Measure the quantity of sand needed to fill this match. Mix thoroughly and, while dry, put through a fine sieve one-half this quantity of burnt sand, one-half new molding sand, and about one-fortieth litharge. Temper the same as molding sand, using boiled linseed oil. Ram up the drag and joint the mold very carefully. Put on the match frame and ram up with the above mixture; strike off, and screw on the bottom board. Remove the drag and allow the match to dry for a day with the patterns left in it. A coat of shellac when dry improves the surface. Fig. 88 shows a set of gated patterns bedded in a hard match.

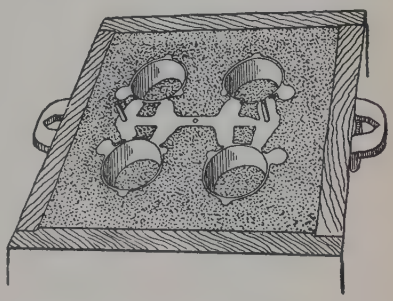


Fig. 88. Oil Match

Use of Molding Machines. *Types.* Although there are many styles of molding machines on the market, these may be classified under four general types as follows: stripping-plate machines; squeezers; roll overs; and jar or jolt-ramming machines. The benefits derived from the use of these machines are manifold.

Advantages. If no consideration were taken of the increase in production possible by their use, the improvement in the quality of castings alone would oftentimes warrant their installation, as the decrease in cost of machining castings produced by this method pays good dividends on the investment. The use of unskilled workmen on these machines is no small item in their favor.

Stripping-Plate Machine. The stripping-plate machine is best adapted to that class of work which offers difficulties in drawing the pattern from the sand.

Fig. 89 shows a pattern for a cast gear mounted on the stripping-plate machine. It is obvious that it would require a considerable degree of skill to produce this class of work by the hand-molding method. The pedestal base of the machine has a flat top. The stripping plate is supported above this by a rigid open framework. Working in guides carried on the sides of this framework is the drawing frame, made to rise or descend by a strong crank and connecting rod. On top of this drawing frame and parallel to the stripping plate is screwed the plate to which the pattern is fastened. The stripping plate is cast with an opening which leaves about 1 inch clear all around the pattern. When both pattern and stripping plate are properly set in place, this space is filled with babbitt metal, this being an easy way to secure a nice fit.

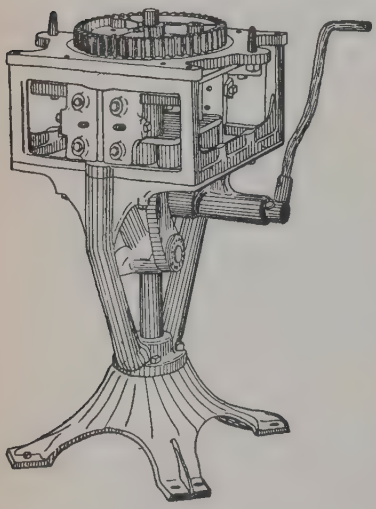


Fig. 89. Typical Molding Machine

In many cases there may be an interior body of sand to be supported when the pattern is drawn. To accomplish this stools are used. A leg screwed into the stool plate supports the stool at the exact level of the stripping plate. The stool plate is fastened to the flat top of the machine inside of the box-like framework which supports the stripping plate, as seen in Fig. 90.

A flask is inverted on the machine, rammed, vented, and struck off. Movement of the crank lever at the side draws the pattern;

and the mold then is removed and set on a level sand floor, thus doing away with bottom boards. A second stripping plate and pattern is used for ramming the cope boxes.

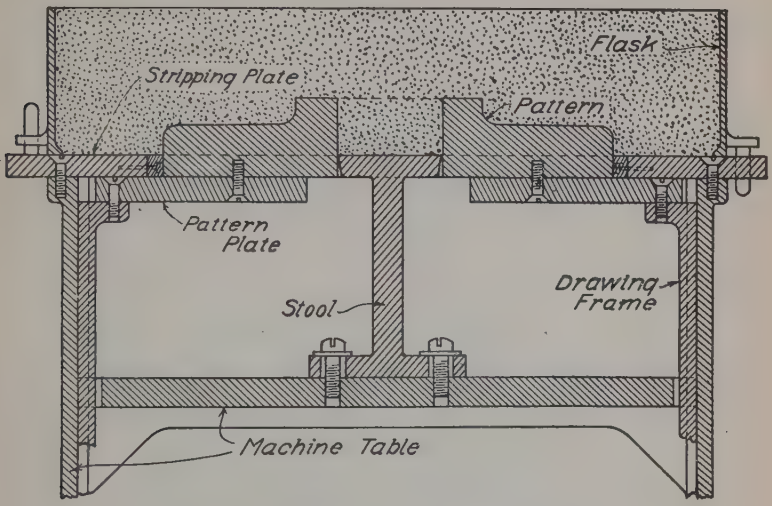


Fig. 90. Molding Stool with Pattern in Place

Pulleys are manufactured on molding machines of this type, as shown by the equipment illustrated in Fig. 91. The rim patterns

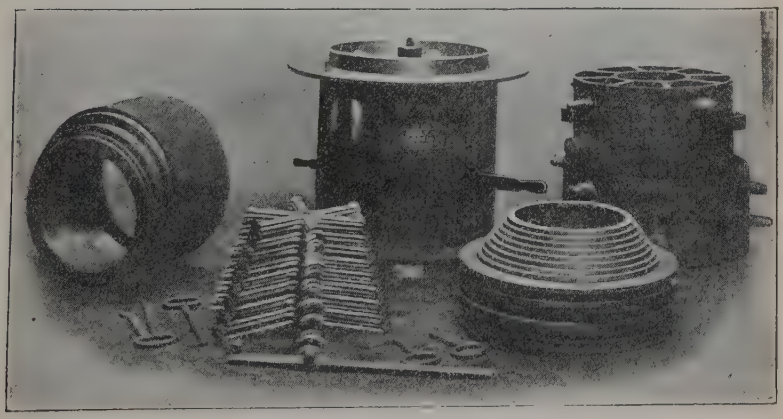


Fig. 91. Pulley Molding Machine

have the form of long hollow cylinders and can readily be set for any desired width of face. The hub carrying the core print separates

from the spokes, lifts off in the mold, and is drawn by hand. The arm patterns are so flat and smoothly rounded that the mold is

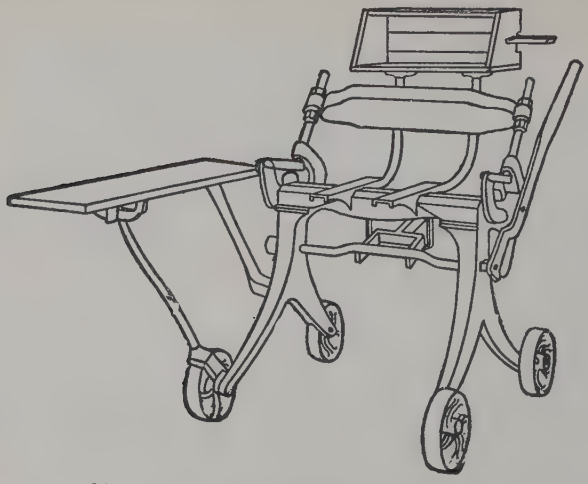


Fig. 92. Simple Molding Machine or Squeezer

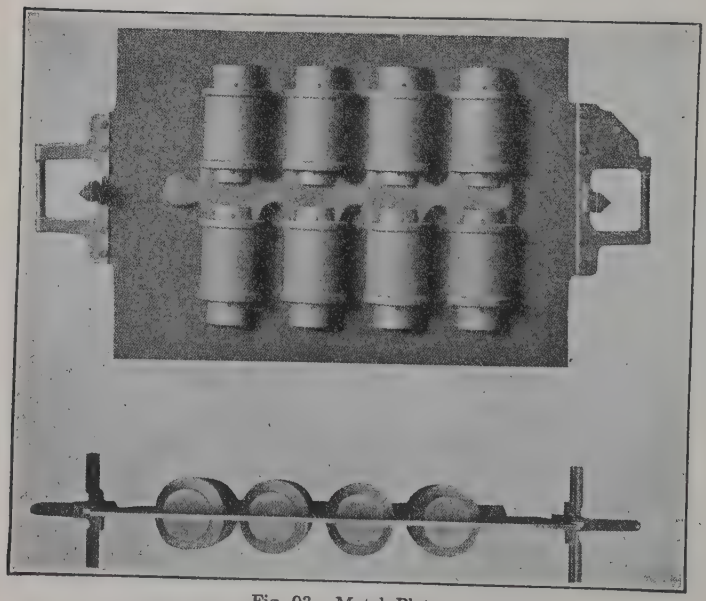


Fig. 93. Match Plate
Courtesy of Tabor Manufacturing Company, Philadelphia, Pennsylvania

easily lifted off of them with little fear of breaking the sand. The cope and drag molds are both alike for a pulley mold.

Squeezer. Fig. 92 shows a type of machine known as the hand squeezer, which only packs the sand. Here the patterns are carried on two sides of a plate set between the cope and drag, as in Fig. 93. Both boxes are filled with sifted sand and set on the machine. The boards are made to follow inside of the flask. The molder's weight on the lever compresses the sand.

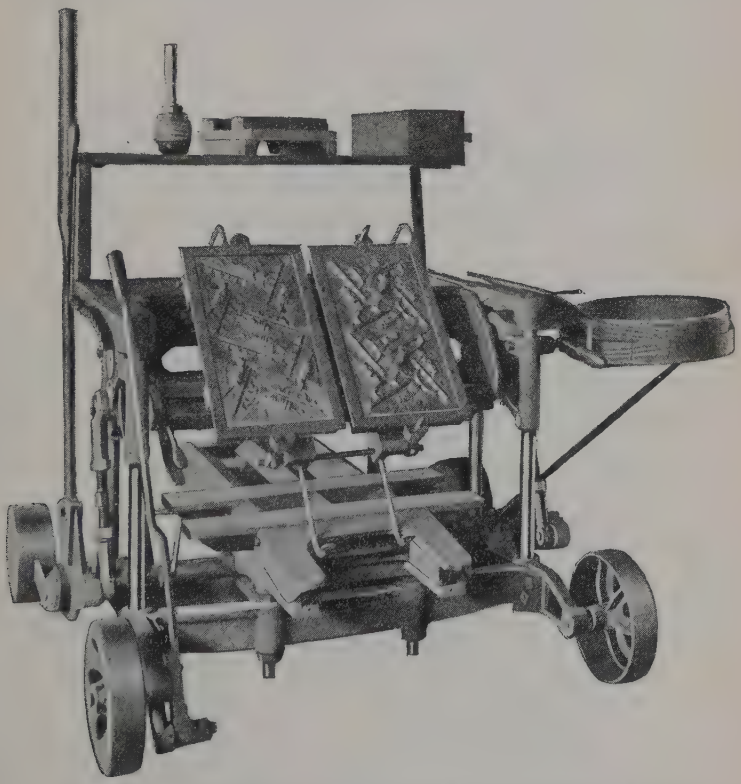


Fig. 94. Hand Squeezing Machine with Cope and Drag Patterns Attached to Portable Table
Courtesy of Arcade Manufacturing Company, Freeport, Illinois

The sprue is cut by a thin hollow steel tube called a sprue-cutter, which is pressed through the cope sand by the molder before separating the flask. In separating the mold the cope is first lifted from the drag, and the plate is gently rapped and lifted from the drag. To make a clean lift when parts of the patterns project in the cope, a second molder raps with an iron bar between the battens of the bottom board while the cope is being drawn off.

Such machines are used chiefly on thin work which vents and solidifies very rapidly—for the outer surfaces of the drag and cope are apt to be rammed so hard that they might choke the vent on heavier castings.

A somewhat different style of hand squeezer is shown in Fig. 94, which shows both cope and drag pattern plates attached to a portable

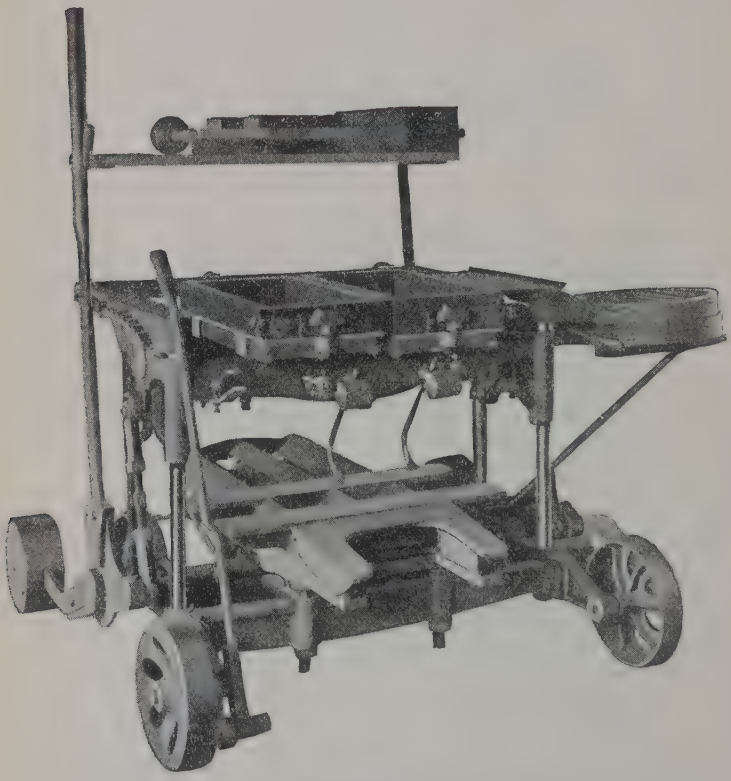


Fig. 95. Beginning the Operation with Hand Molding Machine. Two Halves of Flask in Position

Courtesy of Arcade Manufacturing Company, Freeport, Illinois

table. Beginning the operation, the table holding the plates is turned face up with the two halves of the flask in position as shown in Fig. 95. After the sand is thrown in the flask and the surplus scraped off, the bottom boards are placed in position and held by four clamps. Next, the table is rolled over as in Fig. 96. The ramming or squeezing operation is accomplished by pulling down

the long lever at the left of the machine, as shown in Fig. 97. At this point the clamps holding the cope and the bottom are automatically released.

Fig. 98 illustrates the method of drawing the patterns. The lever is slowly lifted with the left hand, while the operator raps the vibrating pin with a mallet held in the right hand. When the long

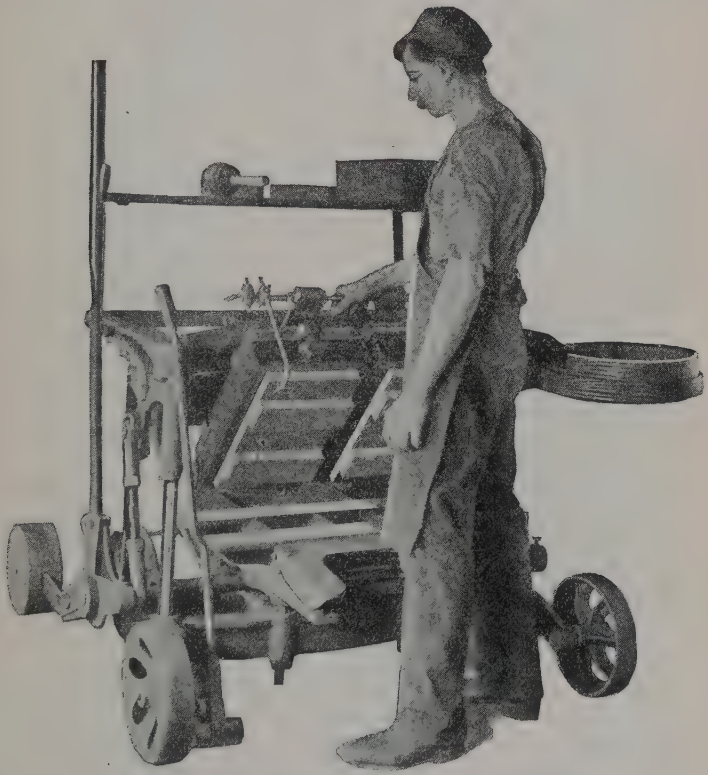


Fig. 96. Table Rolled Over Preparatory to Squeezing
Courtesy of Arcade Manufacturing Company, Freeport, Illinois

lever is returned to its upright position, the two halves of the mold rest on the sliding platform. This is drawn forward in the position shown in Fig. 99. The mold is then closed, the flask removed, and the completed mold carried to its position on the floor for pouring. Snap flasks are best adapted for this style of machine.

Roll Over. The roll-over machine which is illustrated by Fig. 100, has the pattern mounted on a wooden match plate as shown at *A*,

which when in position to receive flask is resting on pins at *BB*. The mold is rammed by hand in the usual manner, the bottom board being clamped on by a special device to the frame *C*. The mold is next rolled over and rests at *A*. The pattern is withdrawn by the use of the foot pedal *E*, the operator meantime rapping the match plate

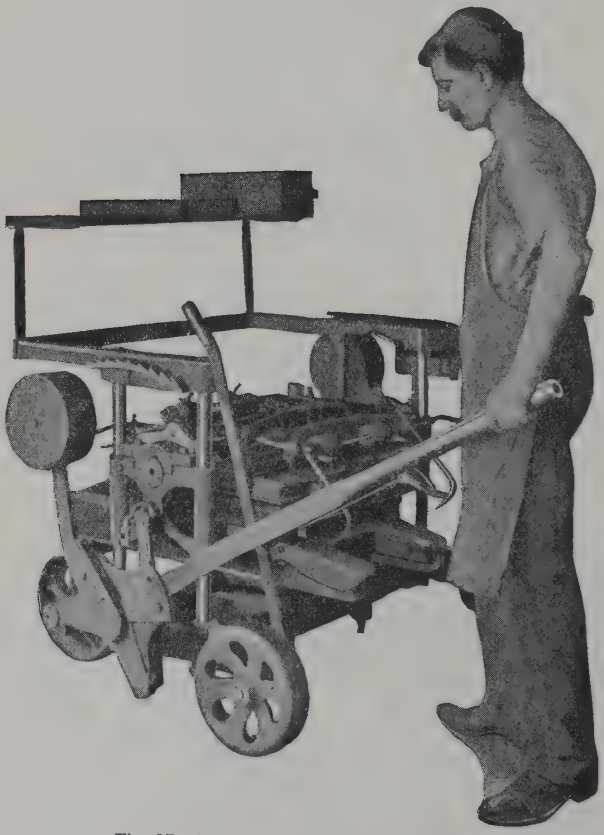


Fig. 97. Ramming or Squeezing Operation
Courtesy of Arcade Manufacturing Company, Freeport, Illinois

with a wooden maul. This type of machine is best adapted to side floor work, the grate bar here shown being a good sample.

Power Operation. The above-mentioned types show only hand machines which have been in general use for a considerable period of time, but the last decade has shown a wonderful change in this branch of foundry practice; indeed so great is the advance that

hardly a month passes that there does not appear some new featuer. The most important advancement, of course, was the adaptation of power, usually compressed air being resorted to, but more recently there has been quite a tendency to utilize electricity.

Power Squeezer. Fig. 101 shows compressed air applied to the squeezer type of molding machine. This machine is designed

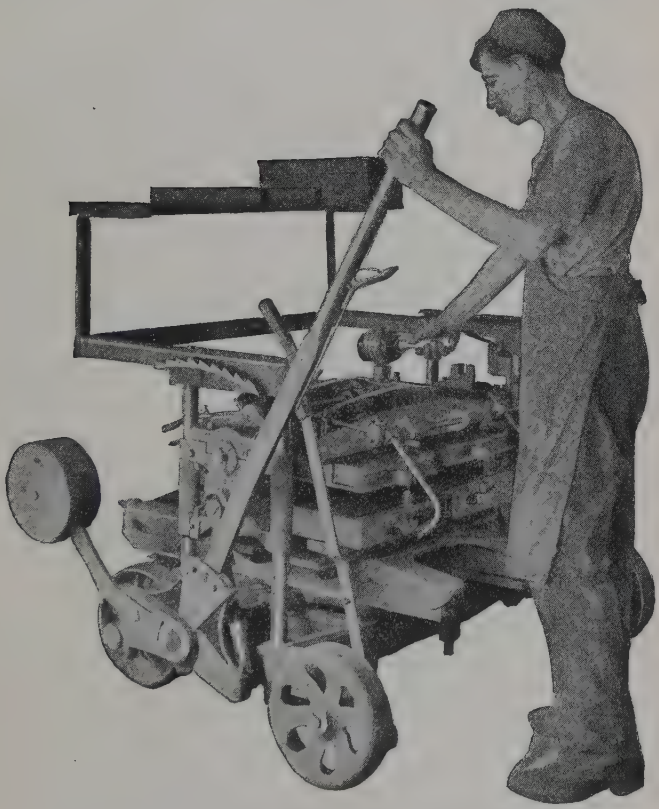


Fig. 98. Drawing the Patterns. Use of Mallet
Courtesy of Arcade Manufacturing Company, Freeport, Illinois

especially for use in molding light snap-flask work in large or small quantities, and the method of pattern fitting depends upon the number of castings to be made from one pattern.

A careful study of the line drawing of this machine shown in Fig. 102 should give a clear understanding of the working parts of the power squeezer, the numbered ones being identified as follows:

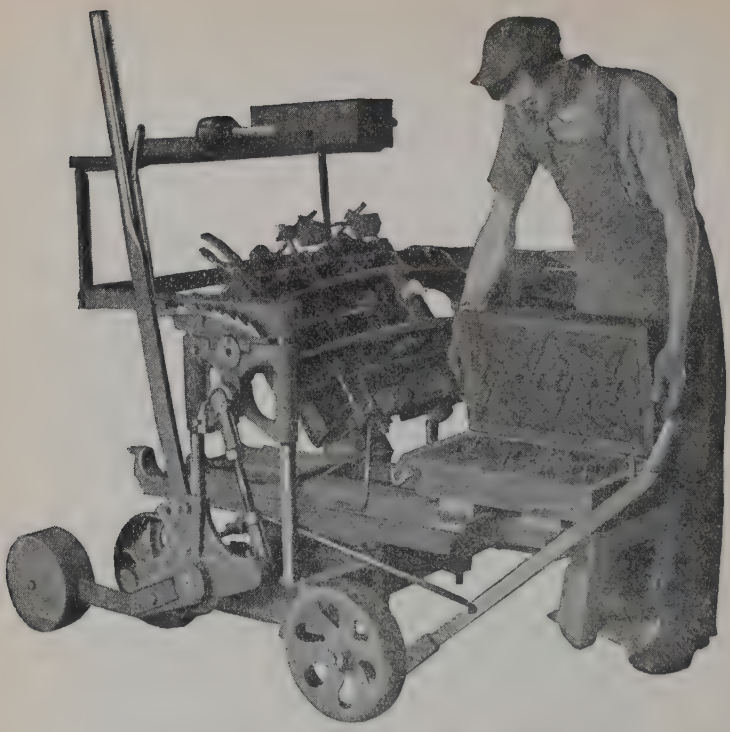


Fig. 99. Two Halves of Mold in Open Position
Courtesy of Arcade Manufacturing Company, Freeport, Illinois

1. Yoke
2. Left-hand stop for yoke
3. Yoke handle
4. Pressure gage
5. ¼-inch air cock
6. Eye bolt
7. Left-hand strain bar
8. Right-hand strain bar
9. Right-hand yoke stop
10. Platen
11. Knee-pad rod
12. Air hose from knee valve to vibrator
13. Air hose from knee valve to supply
14. Hose guard
15. Knee pad
16. Knee starting valve
17. Cylinder base
18. Piston
19. Piston ring
20. Counterbalance spring
21. Adjustment block for spring seat
22. Adjustment-block set screw
23. Trunnion
24. Bracket for lower spring seat
25. No. 5 snap oiler
26. Trunnion shaft
27. Pop throttle-valve lever
28. Valve-lever stud
29. Throttle-stop segment
30. Valve sand guard
31. Valve spring for exhaust
32. Adjustable strain-bar stop
33. Valve body
34. L hose nipple
35. Straight hose nipple
36. Valve bracket
37. Taper pins, trunnion to shaft
38. Blow valve
39. Blow-valve hose

Attention is called to the fact that the production of the power squeezer exceeds that of the hand squeezer by 15 to 30 per cent. For description of various ways of mounting patterns, see Pattern-Making.

Power Roll-Over. A power roll-over power-draft machine is shown in Fig. 103. This is designed to handle side floor work,

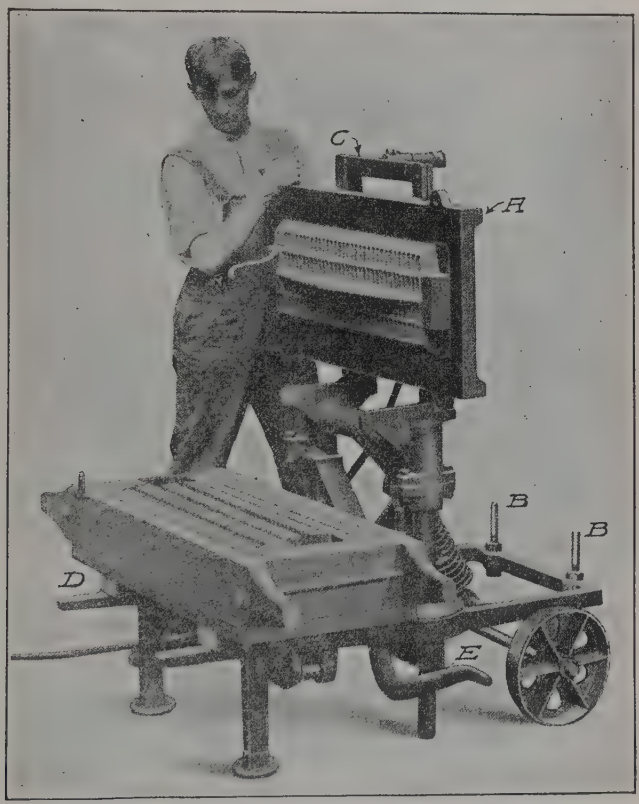


Fig. 100. Roll-Over Molding Machine with Pattern Withdrawn
Courtesy of Tabor Manufacturing Company, Philadelphia, Pennsylvania

and has a straight draft of 8 inches and sufficient power to roll over a weight of 1000 pounds. It will be noted that as in the hand roll-over the patterns are mounted on wooden match plates, the small expense of which makes this style of machine very effective in jobbing shops where but few castings are made from a pattern at a time.

In Fig. 104 is shown the latest type of this machine with the flask shown in position ready for bar ramming. Fig. 105 shows the

mold partly rolled over; the mold rolled over and partly withdrawn is shown in Fig. 106. The view given in Fig. 107 shows the finished mold on one side and the pattern back in place.

The working parts of the above machine are shown in Fig. 108, and are as follows:

1. Roll-over frame
2. Air cylinder
3. Link
4. Wedge leveling device
5. Adjustable support for leveling device
6. Operating valve and lever
7. Vibrator

The plunger is made hollow and acts as an oil tank into which air under pressure is admitted when the machine is to be operated. When air pressure is admitted to the plunger, the oil is forced through

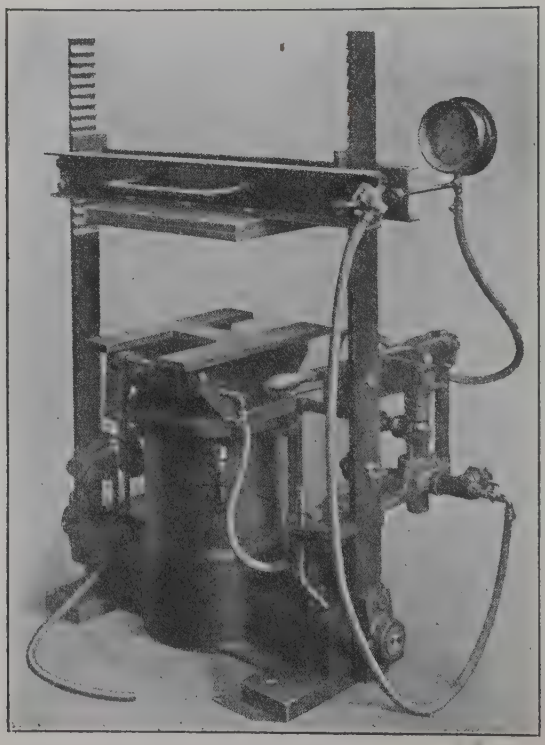


Fig. 101. 10-Inch Squeezer Operated by Compressed Air
Courtesy of Tabor Manufacturing Company, Philadelphia, Pennsylvania

a port into the cylinder, causing the plunger to rise and by means of its link connections to roll over the mold which is deposited on the leveling device. After the flask has been unclamped air is again admitted to the plunger, causing the pattern to be drawn vertically the full draft of the machine, at which point the link

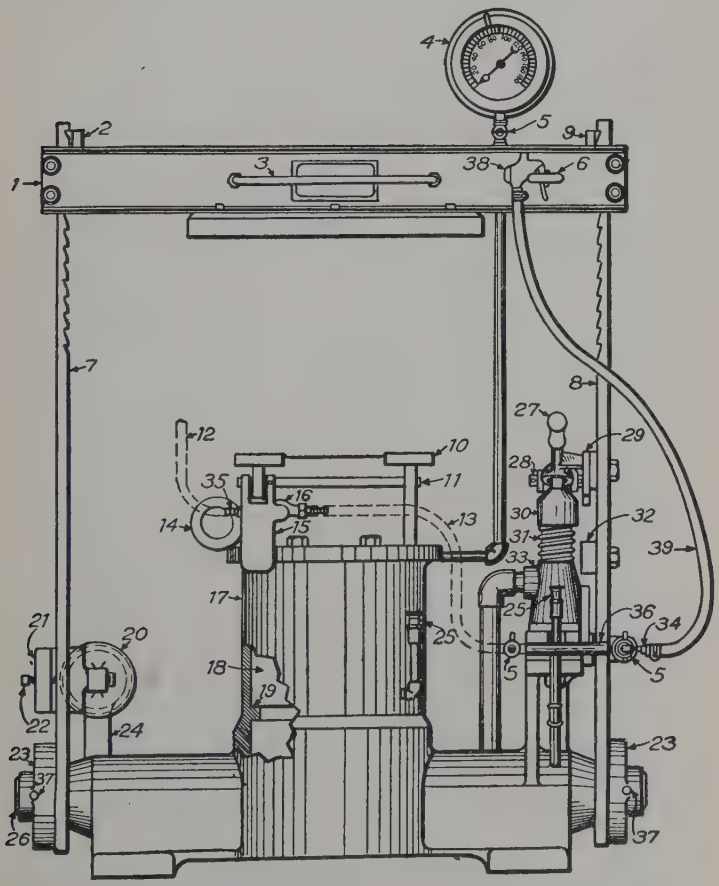


Fig. 102. Elevation of Tabor Squeezer Showing Working Parts

connections cause the roll-over frame to return to its initial position ready to receive another flask.

Jolt-Ramming Machine. The jar or jolt-ramming machine is used for all classes of work from light work up to the largest floor work made in green sand, the limit being only the capacity of the

machine itself, which varies from a few hundred pounds to many thousands of pounds. Large engine beds are a good example of the castings produced on the heavy-duty machines.

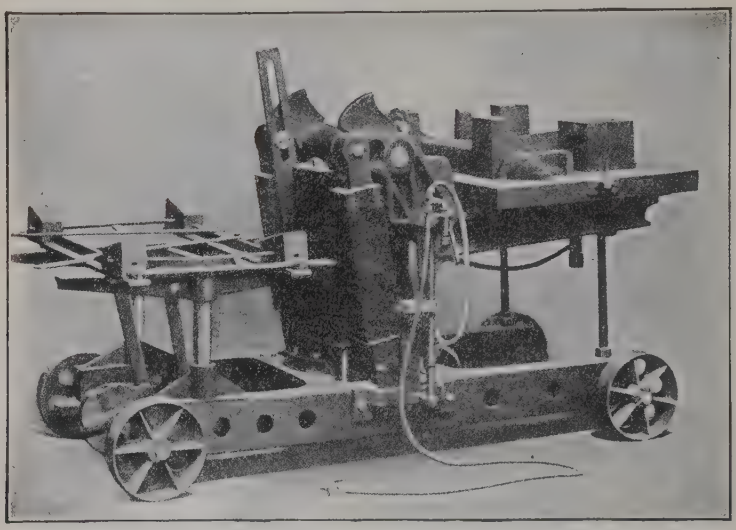


Fig. 103. Power Roll-Over, Power Draft Molding Machine with 12-Inch Straight Draft
Courtesy of Tabor Manufacturing Company, Philadelphia, Pennsylvania

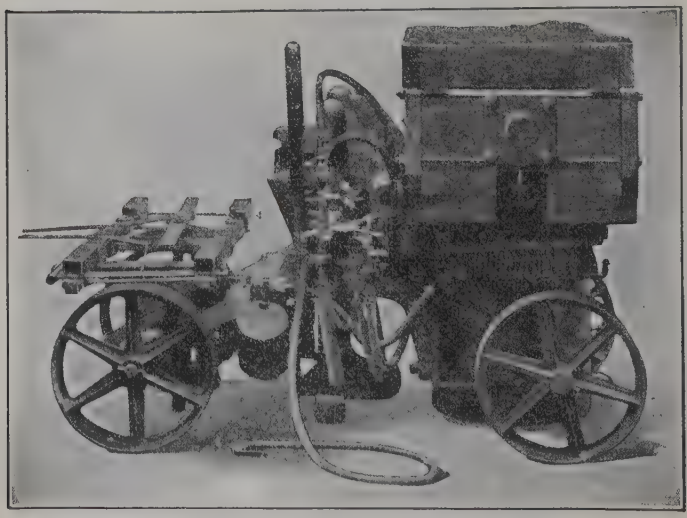


Fig. 104. Latest Type of Tabor Molding Machine with Flask Ready for Ramming

Patterns mounted on heavy wooden match plates are used in the manner hereafter described. The flask is first placed on the drag

half of the pattern board, and the flask filled with sand. By the use of an upset, usually about 4 inches deep, it is possible to heap sufficient sand on the flask to insure its being filled after the ramming has taken place. The flask must be securely clamped to the pattern plate, when both may be listed by the traveling crane and placed on the table of the jarring machine, which in the heavy-duty machines is on the foundry-floor level; the working parts of the machine being below and resting on a rigid concrete foundation. Here, air under

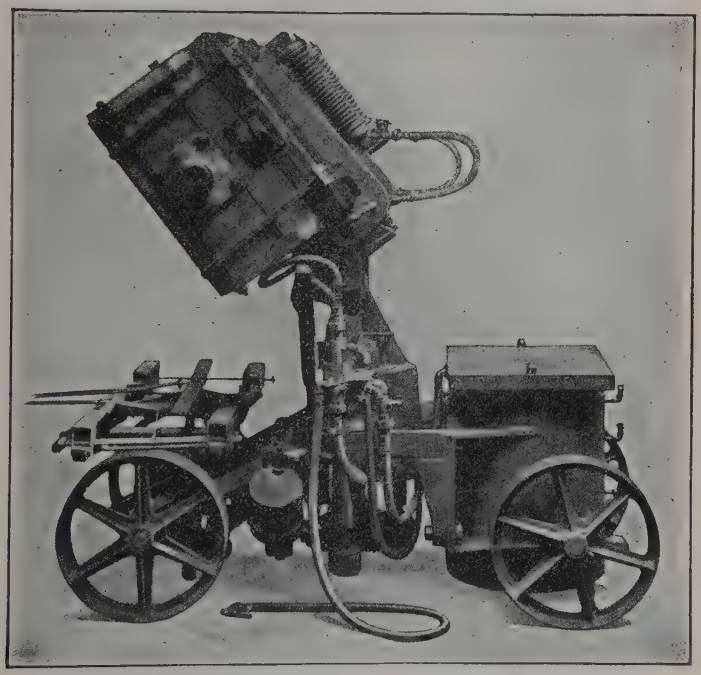


Fig. 105. Machine with Mold Partly Rolled Over
Courtesy of Tabor Manufacturing Company, Philadelphia, Pennsylvania

pressure is allowed to enter the cylinder, and, acting on the plunger, which in turn lifts the table usually about 4 inches, when the air is suddenly exhausted, allows the table to drop heavily on the anvil. The number of blows required to pack the sand must be determined by experience. The time required to ram the largest mold is but a small fraction of that consumed by hand-ramming.

Fig. 109 is an illustration of one of the simplest styles of this type of machine. Fig. 110 shows the working parts of the same machine.

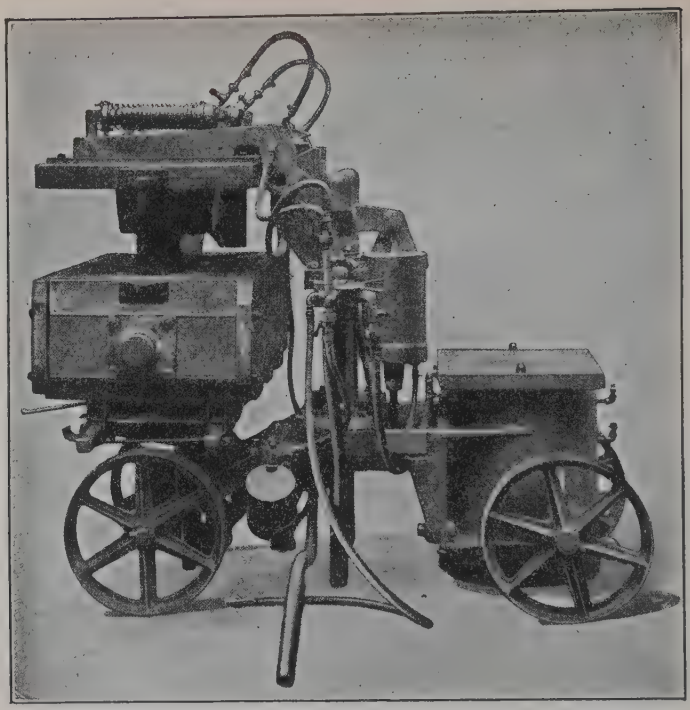


Fig. 106. Mold Completely Rolled Over and Partly Withdrawn
Courtesy of Tabor Manufacturing Company, Philadelphia, Pennsylvania

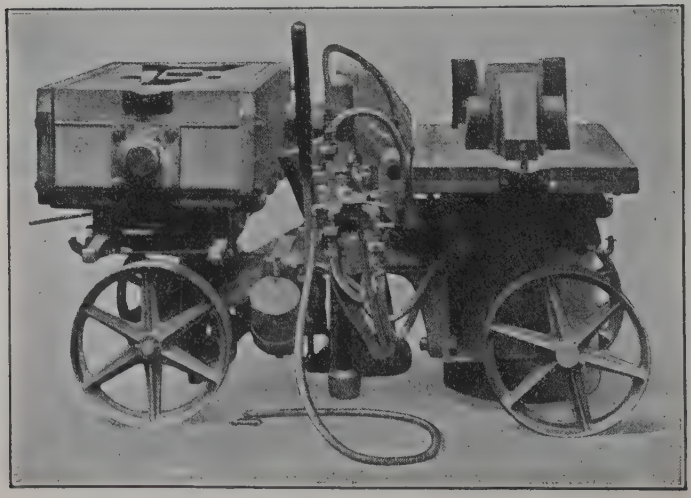


Fig. 107. Finished Mold on One Side and Pattern in Place
Courtesy of Tabor Manufacturing Company, Philadelphia, Pennsylvania.

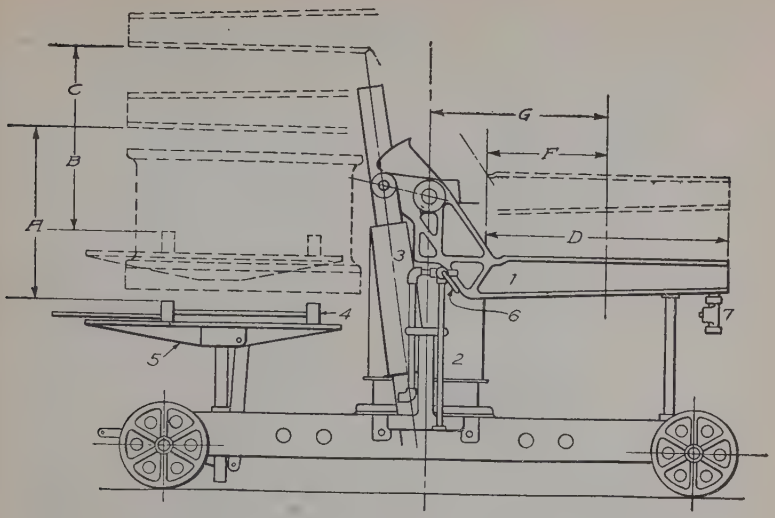


Fig. 108. Diagram of Working Parts of the Tabor Molding Machine

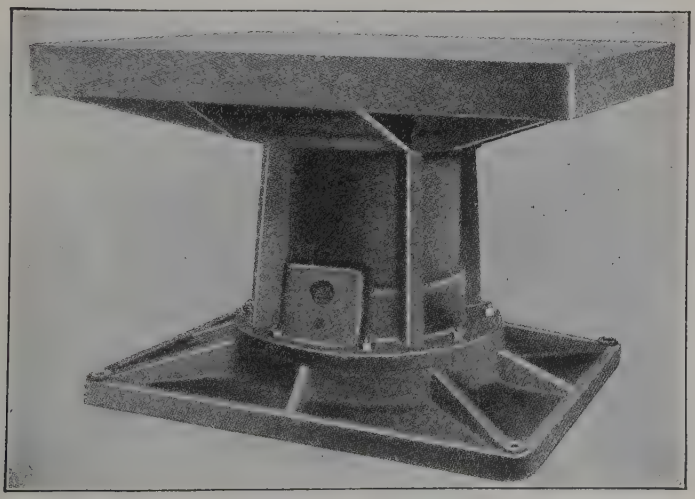


Fig. 109. Simple Type of Jolt-Ramming Machine
Courtesy of American Molding Machine Company, Terre Haute, Indiana

A quite distinct style of jolt machine, called an electropneumatic jolt-ramming machine, is shown in Fig. 111, the unique feature being the motor-driven compressor without a clutch, spring, cam,

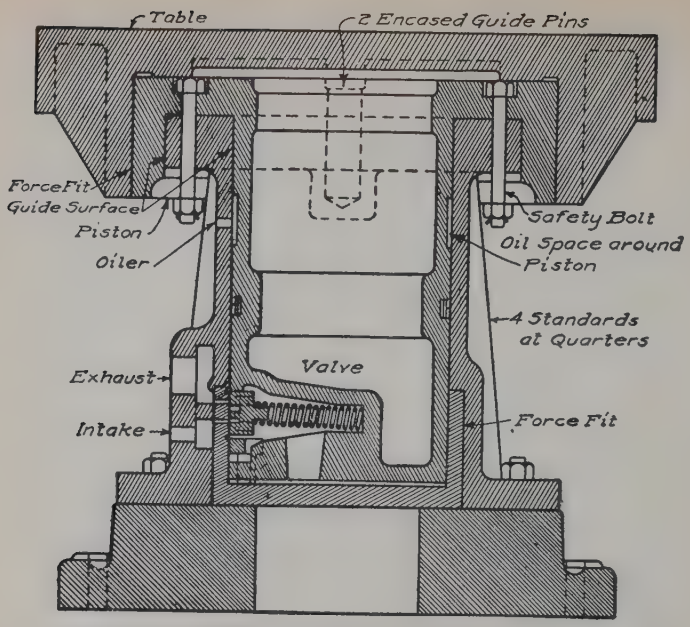


Fig. 110. Section of American Jolt-Ramming Machine

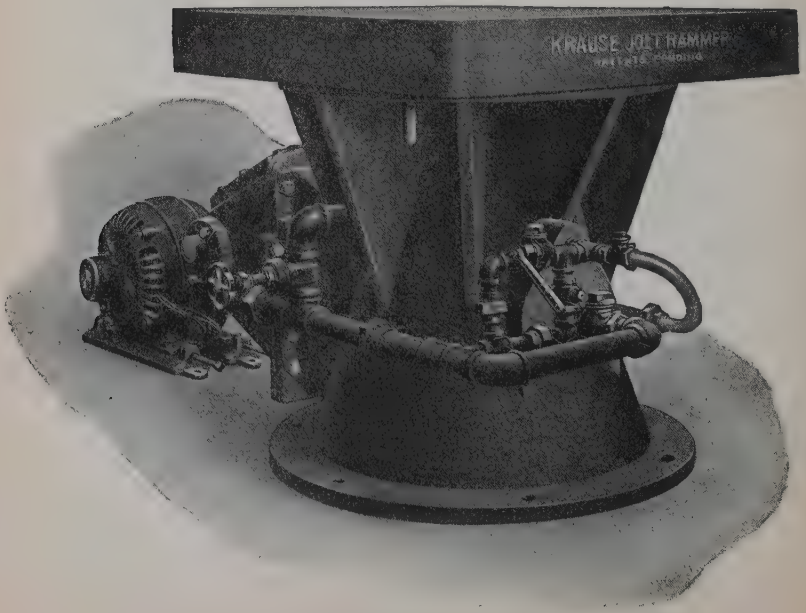


Fig. 111. Krause Electropneumatic Jolt Rammer
Courtesy of Vulcan Engineering Sales Company, Chicago, Illinois

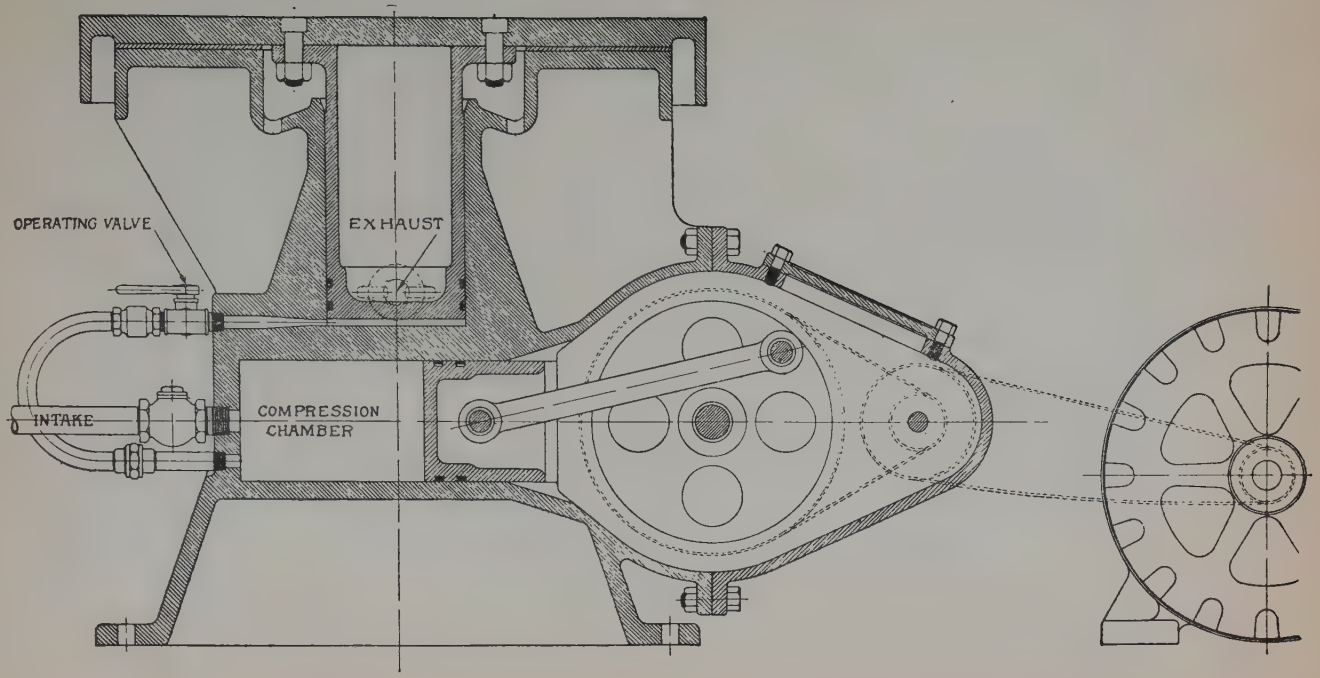


Fig. 112. Section of Krause Jolt Rammer Showing Transmission and Unique Compressor

or valve. A very little study of Fig. 112 should make clear its radical features.

Automatic Squeezer. Fig. 113 illustrates an automatic molding machine of the squeezer type. The operator places the flask and bottom board in position, then by simply pressing on the starting lever the filling of the flask with sand, the ramming and the drawing of the pattern is completely automatic and accomplished in about

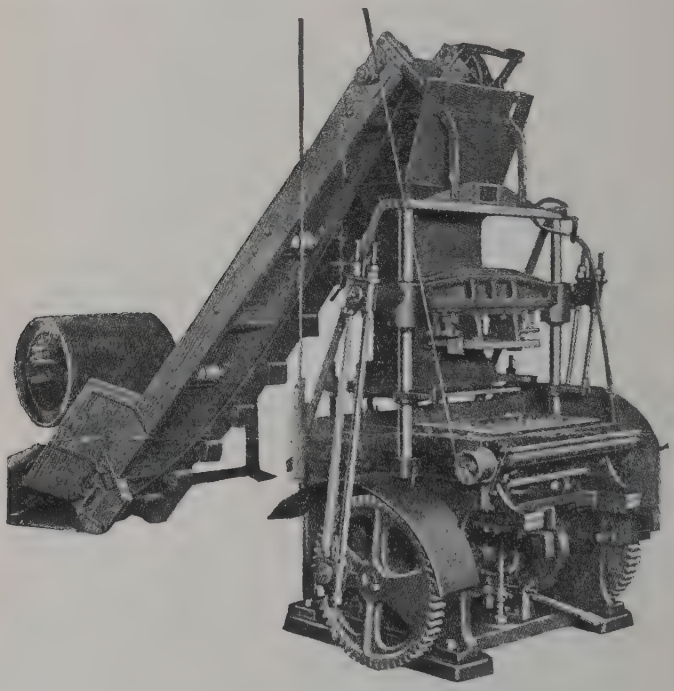


Fig. 113. Automatic Molding Machine of the Squeezer Type
Courtesy of Berkshire Manufacturing Company, Cleveland, Ohio

eight seconds or some six or seven hundred molds per day. This machine is best adapted to the production of small duplicate work such as small pipe fittings.

Roller-Ramming Machine. The very distinctive type of molding machine shown in Fig. 114 is known as the roller-ramming machine. It is best adapted to long work of comparatively thin cross-section, of which a cornice section would be a good example. This class of work could not be produced readily on any of the

previously mentioned types of machines. Fig. 115 is a detailed drawing of Fig. 114.

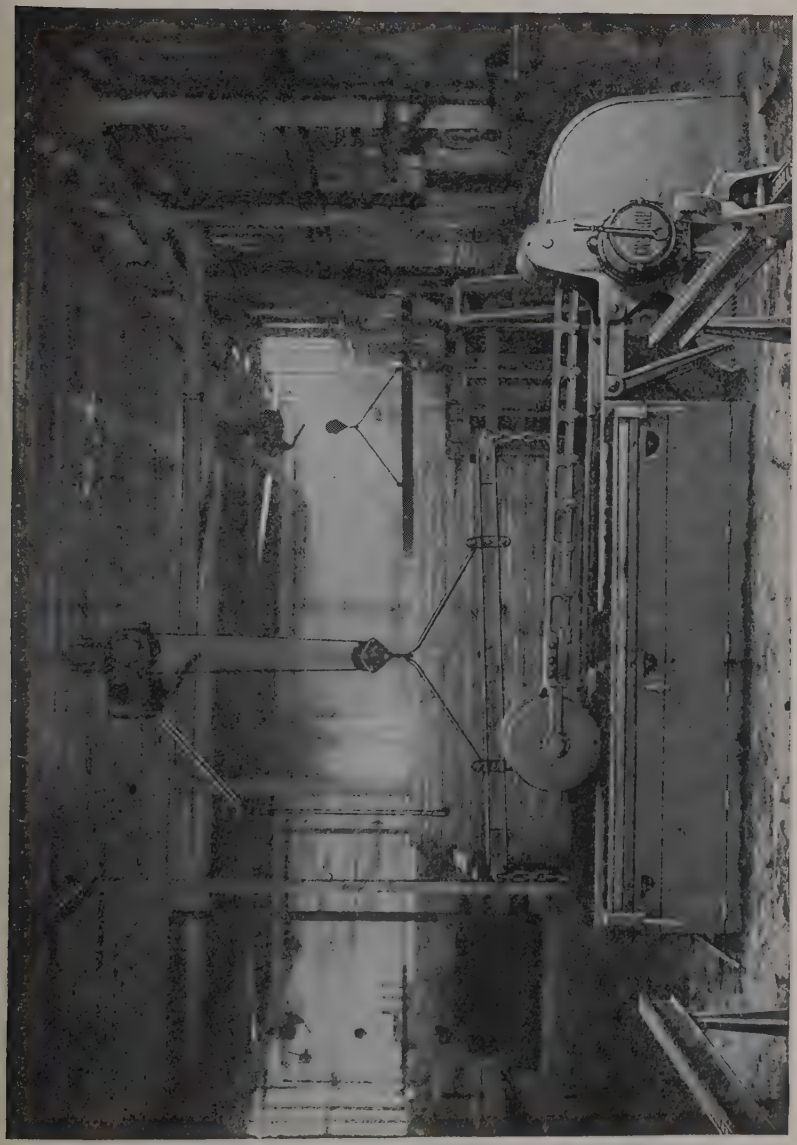


Fig. 114. Moldar Roller-Ramming Machine in Operation
Courtesy of Richm, Browne and Donald, Maspeth, New York

The success of any and all molding machines depends on the intelligent selection of the type best suited for the work in hand.

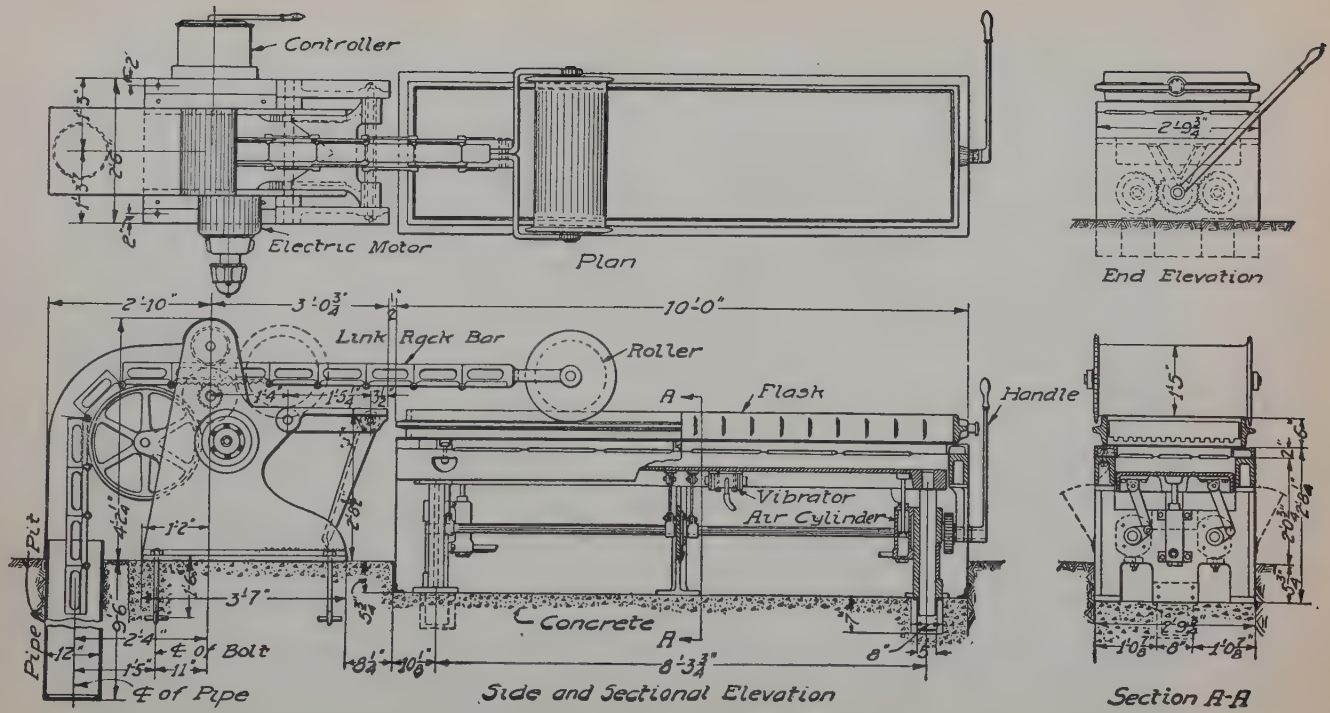


Fig. 115. Plan and Elevation of Moldar Roller-Ramming Machine

DRY-SAND WORK

Characteristic Features. This branch of molding becomes a separate trade in shops where the work is done continually. The dry-sand molder must use the same precautions as the green-sand molder in setting gates and risers, and in fastening his sand with crossbars and gaggers. At the same time, he works with a core-sand mixture next his patterns and backs this with a coarse molding sand, so that he must combine the skill and judgment of both the green-sand molder and the core maker. The venting of dry-sand work must be ample, as in the case of cores, but it is simpler than in core work, because the core mixture surrounds the casting so that vents may be taken off in all directions.

Iron flasks are used, generally provided with trunnions to facilitate turning. The facing mixture is the same as that used for making large cores, as discussed in the section on Core Work; the remainder of the flask is packed with the same sand after it has been used. The patterns are made and used the same as with green sand, only they should be brushed over with linseed, crude-oil, or other heavy oil, before ramming. In some shops oil is brushed over the joint before parting sand is thrown on. After the pattern is drawn, the mold is finished by applying a heavy coat of good black wash. When the sand has absorbed the moisture so that all glisten has disappeared, this blacking is slicked over. Great care must be exercised in this operation, for too much slicking will draw the moisture to the surface again and result in scabs on the casting.

Molding Engine Cylinder. Engine cylinders are a representative line of work for dry sand. Consider a simple type of cylinder, such as shown in Pattern-Making, Fig. 244, to have a bore of from 16 to 26 inches, and with the exhaust-outlet flange placed above the center of the cylinder. To facilitate setting the cores, the pattern may be split through the steam chest. The flange just mentioned should be molded in the drag, and should be made loose and draw in the opposite direction from the main pattern. The cylinder core should be made on a barrel, as will be explained later, and the mold poured on end to insure sound metal and to reduce the casting strain on the port cores. The flask is made with a round opening in one end to allow the core to project through it. This opening is larger than the diameter of the core to allow for

gates and risers. There must be another opening at the side of the flask adjacent to the steam-chest core to provide for fastening these cores. Iron plates serve for flask boards and there should be a hole in the drag plate in line with the exhaust core to allow for venting and fastening its end.

One-half of Fig. 116 shows the end view of the flask. The other half shows a section through the middle of the completed mold. Here *A* is the hollow cylinder core, *B* is the chest core, *C* the live-steam core hung in the cope, and *D* the exhaust core. The flask is packed in a manner similar to green sand.

Use of Cover-Core. The method of molding the exhaust flange, however, has not previously been explained. To do this,

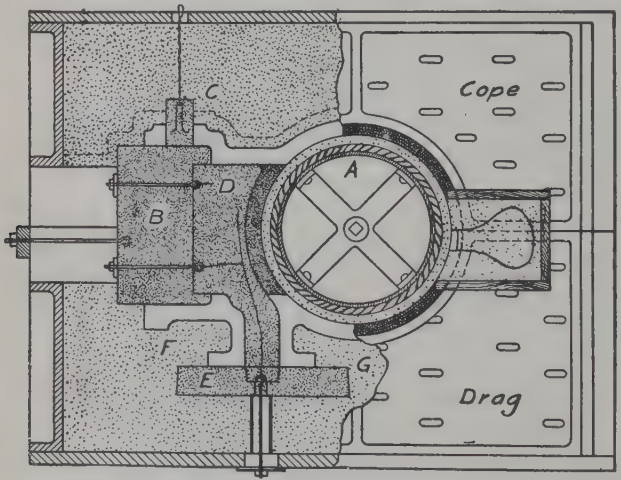


Fig. 116. Molding a Cylinder

proceed packing the drag until the pattern is covered. Tuck the facing carefully underneath the flange, setting in rods as in core work, to strengthen the overhanging portions. Make a flat joint, *FG*, at the level of the top of the flange, then carefully fit over the print of the flange the cover-core *E*, and fix its position with nails driven into the joint at its corners. Now remove the cover-core, draw the flange, and finish that part of the mold with black wash and slicking. When this is accomplished, replace the cover-core, place a short piece of pipe over its central vent, and finish ramming the drag. This method may be used in many cases, both in dry-sand

and in green-sand work where a small detail of the casting requires a separate joint surface.

A sectional plan looking down on the drag is shown in Fig. 117. When the mold has been properly finished and baked, the drag is brought from the oven and set on a pair of stout horses. The cylinder core is first set in place, then the exhaust core is set in its

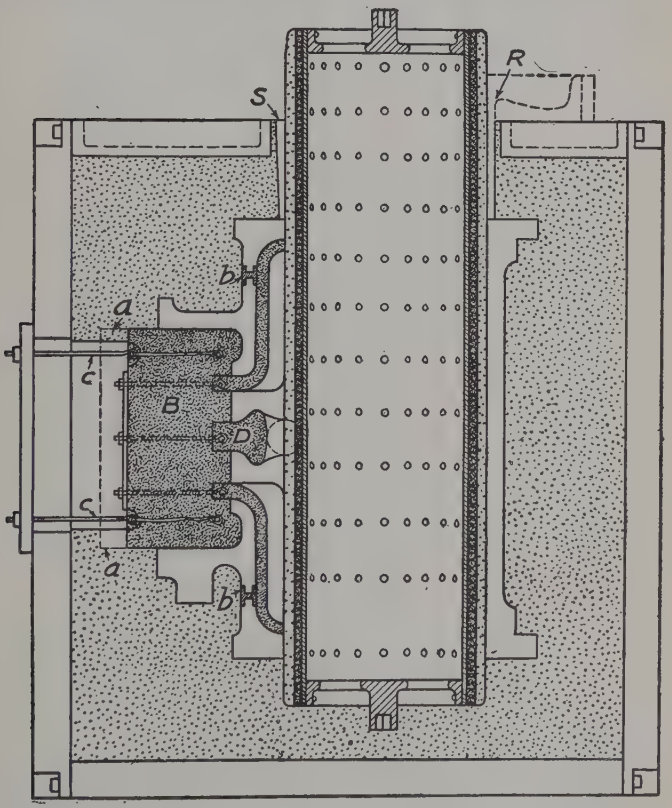


Fig. 117. Sectional Plan of Fig. 116 Looking Down on Drag

drag print and held close to the cylinder core, while the port and chest cores, previously pasted and fastened, are lowered into the chest print. The chest print is cut a little long at *aa*, to allow its core to be drawn back slightly, while the exhaust core is entered into its place between the port cores. Then all of the cores are set forward into position, the chaplets *bb* set, the space *aa* tightly packed again, and the anchor bolts *cc* placed in position and made fast.

The drag print of the exhaust core is made fast from underneath the drag plate. When all the cores have been firmly fastened, the cope is closed on, and the two boxes clamped at the flanges and set up on end. The runner *R* and the riser *S* were cut and finished before baking; the basins must be built in green sand after the mold is closed.

Making Barrel Core. Loam is used here for the outer shell of the core. It is probably the simplest job in which a loam mixture is employed, and is made by a core maker more frequently than by the higher paid loam molder. Barrel cores are used where the core is long and can best be supported at the ends only; for example, in gas and water pipes and cylinder work.

Loam. Loam is a facing mixture, of the consistency of mortar, applied to the face of the core or mold. It contains fire sand with a bond of strong porous molding sand moistened with a thick clay wash. A small proportion of organic matter in the shape of horse manure is put in to aid the bond and to leave the crust of loam more fragile by burning out as the casting cools. Proportions of the mixture will vary according to locality, but the principles already cited hold here as with other molding compounds. With too much bond the loam works easier but tends to choke the vents when casting. With not enough it is weak and is liable to break, cut, or crumble under strain. A typical mixture is as follows:

Loam Mixtures

Material	Mixed by Hand (parts)	Mixed by Mill (parts)
Fire sand	10	10
Strong coarse molding sand	4	3
Horse manure	1½	2
Temper	Thick clay wash	Thick clay wash

The advantages of loam cores are that they are lighter, cheaper to make, and carry off the gases faster than do dry-sand cores.

Method. The method is as follows: A piece of pipe about 3 inches smaller than the outside diameter of the core is selected to form the center. The pipe is perforated with a large number of holes. If the pipe is more than 3 or 4 inches in diameter, centers

or trunnions are riveted in the ends to serve as bearings. The pipe is arranged to revolve freely on a pair of iron horses, as shown in Fig. 118. A crank handle is attached by which the pipe may be turned. A couple of wraps of hay rope are first given around one end of the pipe, and the loose end is pinned flat by a nail run under these strands. Tight wrapping is then continued to the other end of the pipe, where the rope is fastened in a similar manner and cut off. Hay rope should be made of long wisps tightly twisted. Sizes vary from $\frac{3}{4}$ to 1 inch. Where only a small amount of hay rope is used, it is bought ready made. Foundries using large quantities

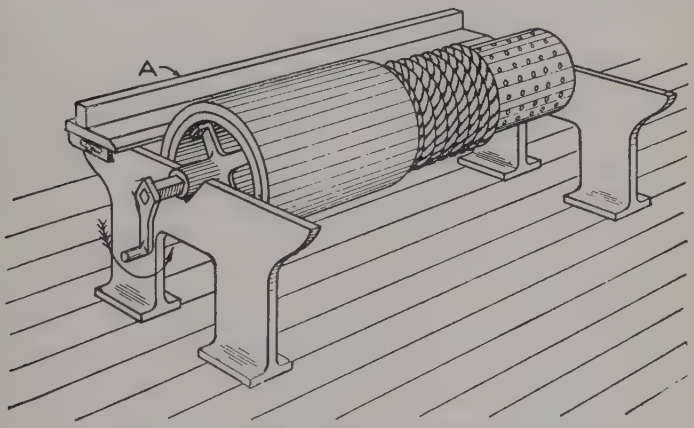


Fig. 118. Making Loam Core for Cylinder

are equipped with one or more machines built especially for making this rope.

The first coat of loam is rubbed on with the hands, then well pressed in with the flat side of a board as the barrel is slowly revolved. When this has set, the core board *A* is placed in position, and the roughing coat worked on to the core to within about $\frac{1}{4}$ inch of finished size. The core is now dried in the oven. Placing the core again on the standards, the finishing coat of slip is applied with the core board while the core is still hot. The diameter is tested with calipers and brought to required size by slight adjustment of the sweep board *A*. When the core has been built to size, move the loam back from the edge of the board *A*, then withdraw the board while the barrel is still in motion.

Slip. Slip or skinning loam is made by thinning regular loam as it is rubbed through a No. 8 sieve. The heat of the core is usually sufficient to dry this slip coat enough so that black wash may be brushed on and slicked, as in dry-sand work, before running the core into the oven again for its final baking.

The service of the hay rope on a barrel core is twofold: it furnishes a surface over the smooth metal of the barrel to which loam will adhere; and it is elastic enough to give as the casting shrinks around the core. The hay slowly burns out after the casting has set, and this frees the barrel so that it can easily be withdrawn and used again.

LOAM MOLDING

Skill Required. The loam molder requires the greatest all-around skill in the whole range of foundry work. He must know all the tricks of the core room and dry-sand shop, and most of those in green sand. Added to all this he must have a practical working knowledge of the principles of drawing and must possess to a large degree the foresight of the designer.

In order to save time and lumber in the pattern shop, only a set of sweeps is provided if the mold is simple, and these, with blue prints of the piece wanted, are all the molder has to work from. In intricate work, such as a modern Corliss cylinder, a skeleton pattern carrying the steam chests, etc., in accurate position is made, and in some very crooked work a pattern is furnished complete. As a rule, however, the loam molder must rely upon his own skill and ingenuity for the best method of constructing each detail of the work.

Rigging. The equipment for the loam floor varies in different shops. In Fig. 119 are shown the essential features of an equipment for sweeping-up circular forms.

Spindle. The spindle *a* should be large enough not to spring when being used, and long enough to conveniently clear the highest mold. A piece of 2-inch shafting is a handy size, for with it the sweeps may be made uniformly 1 inch less than the required diameter and placed snug to the spindle when set up, and the correct size of mold is ensured. This spindle should revolve smoothly in a step *b*. The step shown may be set at any convenient place on the floor. It has a long taper bearing, as shown in section *A*, capable of holding a 5-foot spindle without need of any top bearing. The three arms serve to

make the step set firmly, and upon them any plate may be readily leveled up. Where a tall spindle is used, the spindle socket is more shallow; the step may be cast without arms and be bedded in the floor. The top of the spindle is steadied by the bracket *c*. This must carry a bearing box so designed that the spindle may be readily set in position or removed. And the bracket must swing back out of the way when any parts of the mold are to be handled by the crane.

Sweeps. The sweeps are attached by means of the sweep arm *d*. The detail *B* shows one method of clamping the sweep arm to the spindle by using a key. The arm is offset so that one face hangs in

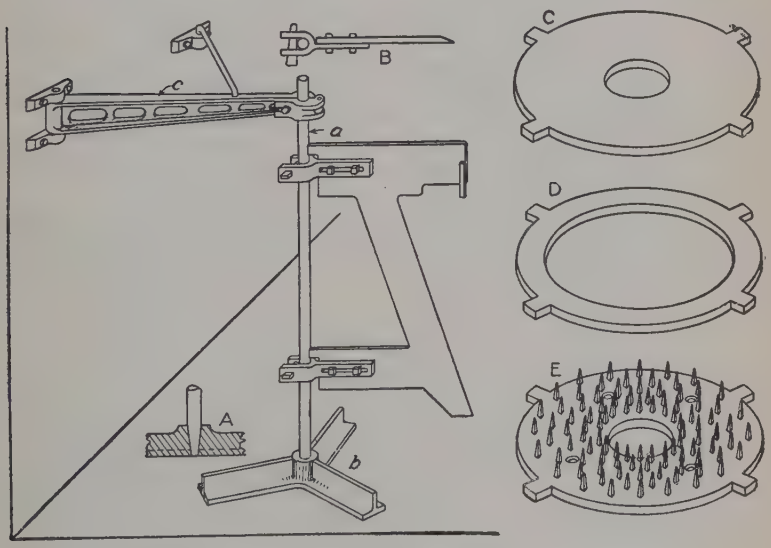


Fig. 119. Rig for Loam Work

line with the center of the spindle. Bolting the face side of the sweep to this brings the working edge in a true radial plane. Sweeps are usually made from pine about $1\frac{1}{8}$ inches thick. The working edge is cut to the exact contour of the form to be swept, and then is beveled so that the edge actually sweeping the surface is only about $\frac{3}{8}$ inch. For very accurate work or when sweeps are to be much used, the edge is faced with thin strap iron to prevent wear.

Plates. We have seen that the walls of green- and dry-sand molds are supported by sand packed into flasks and that these flasks may be lifted, turned up sideways, or rolled completely over to suit

the convenience of the workman. The facing which forms the wall of a loam mold is supported by brickwork built upon flat plates of cast iron, and laid in a weak mortar of mud. From the nature of their construction, therefore, these molds must always be kept perpendicular when being handled. The parts may be raised, lowered, or moved in any direction horizontally, but they must not be tipped or rolled over.

The plates are cast in open sand molds, as illustrated in Fig. 56. Two methods are employed to provide for handling them by the crane;

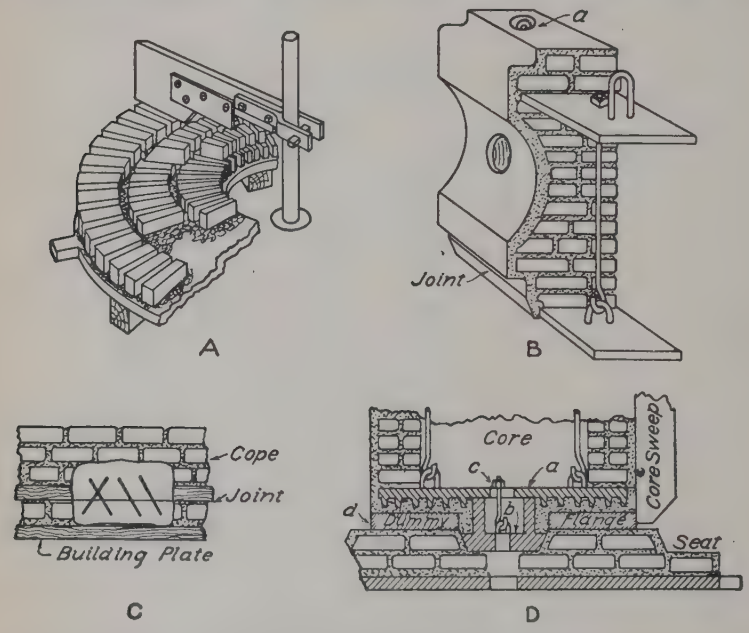


Fig. 120. Laying-Up Loam Work

either lugs are cast on the edges of the plates, as in *C*, *D*, and *E*, Fig. 119, or wrought staples are cast in the plates, as shown in *B*, Fig. 120, or in the crown plate of the main cylinder core, Fig. 123.

Three typical plates for a loam job are shown in Fig. 119. *C* is the building plate; it should be at least 18 or 20 inches larger than the largest diameter of the casting to be made, and thick enough to support the weight of the entire mold without springing. *D* shows a cope ring; its inside diameter should clear the casting 2 inches on all sides. The face should be 8 to 12 inches wide, depending upon

the height of the mold. *E* shows a cover plate; its diameter equals the outside diameter of the brickwork on that part of the mold which it covers. Here the loam facing is placed directly on the iron, and must be supported when the plate stands vertically or is turned completely over as in *C*, Fig. 122. To hold the loam in this way, fingers or stickers are cast on these plates. This is accomplished by simply printing the end of a tapered stick into the bed of the open mold which

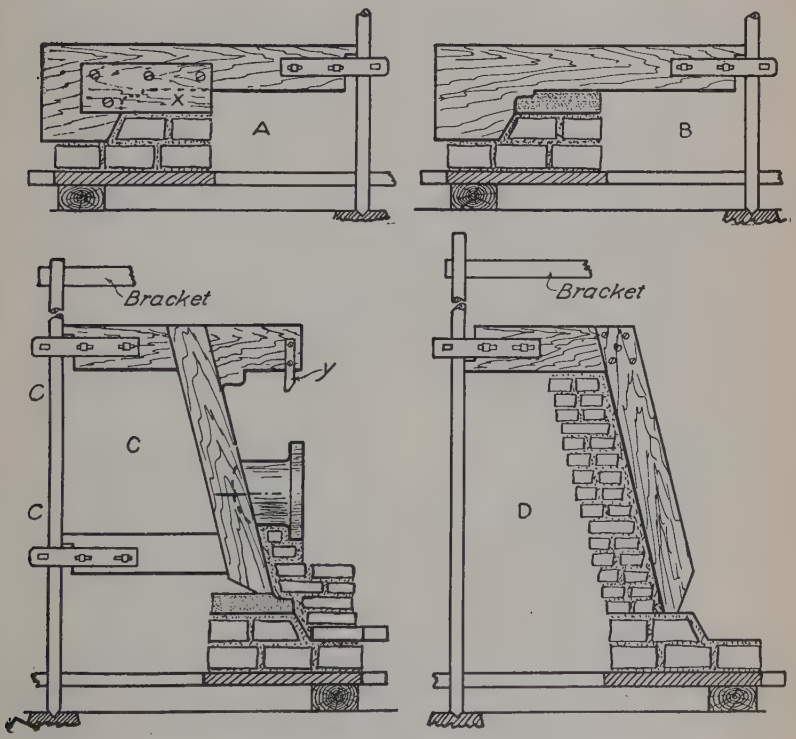


Fig. 121. Steps in Sweeping Up Type Mold

shapes the plates. These sticker plates are often used for a purpose similar to the core *E*, Fig. 116, and shape the outer face of a picked-out flange. This is illustrated in *D*, Fig. 122.

Materials. *Brick.* Common red brick is best for making loam molds, Figs. 120 to 123. It should be free from glaze and have a uniform texture, so that the pieces will break clean when it is necessary to fit them to the shape. An old 12-inch half-round file makes a handy tool for cutting these. Sometimes brick is molded

up from loam, and air-dried. It is much more fragile than red brick, and may be used in pockets, or where the shell of the casting is quite thin, and ordinary brick might resist the shrinkage strain to such an extent as to endanger cracking the casting.

Mud. For laying up the brickwork, mud is used, loam facing being applied only to those surfaces which come in actual contact

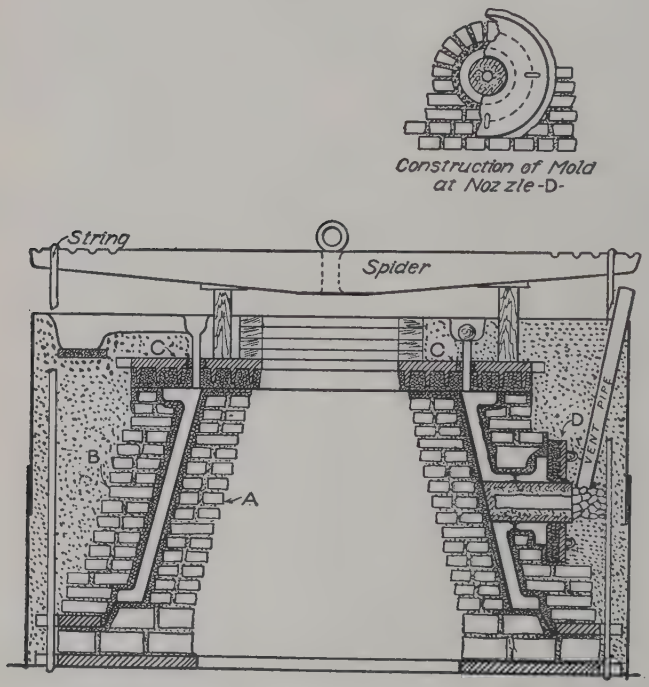


Fig. 122. Complete Typical Loam Mold

with the iron. Mud is made from burnt loam or old floor sand, mixed with clay wash to the consistency of mortar.

Facing. The composition of loam facing and slip have already been given under the description of making a barrel core.

Cinders. Cinders are an important material in this work. Their size will depend upon their position in the mold. For working in between brick, the cinders should be crushed if necessary, put through a No. 4 sieve to remove smallest pieces, then passed through a No. 2 sieve to remove the larger pieces.

Principles of Work. *Parts of Mold.* The names of the main parts of a loam mold differ somewhat from those applied when molding in flasks. As will be seen from the section, Fig. 122, there are three main divisions in the mold: *A*, which corresponds to the drag in a three-part mold, is called the *core*. *B*, which corresponds to the cheek, is called the *cope* in loam work. And *C*, which serves the same purpose as the cope of a green-sand mold, is spoken of as the *cover* in loam molding. When the central core is actually made a separate piece, as in Fig. 123, the lower part of the mold is called the *bed* or *foundation*.

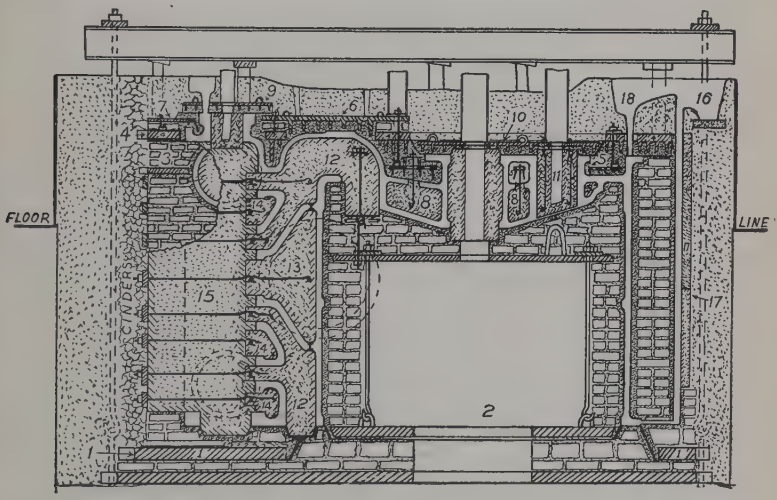


Fig. 123. Loam Mold for Marine Cylinder

Laying-Up. In laying-up a loam mold, Fig. 120, set the plate central with the spindle and approximately level. Then set the sweep and finish leveling the plate until repeated measurements at the four quarters of the circle show a uniform space between the lower edge of the sweep and the surface of the plate. For the building plate this measurement should be 5 inches; for a sticker plate the sweep should clear the sticker points by $\frac{1}{2}$ to 1 inch according to the thickness of the casting.

The hands are used in spreading mud or loam upon the plates or brickwork when building the mold. The brick must always be set well apart, leaving a space at least the width of a finger between them. Fill in these spaces with fine cinders. The reason for this is

fourfold. It facilitates drying; it provides good vent; it gives or crushes sufficiently when the casting shrinks not to cause undue strain; and it reduces the labor in cleaning. In each course of brick the joints should lead as directly as possible away from the casting, but the joints should be broken between courses. These points are illustrated in the sketch *A*, Fig. 120. As shown, the first two courses of the core are usually set edgewise. For the rest of the core and for the cope, the bricks are laid flat. These bricks run lengthwise around the circumference, with a course of headers about every four to six courses.

Venting. Cinders between brick form the ordinary means of leading the vent from the loam facing. In confined places or pockets, as, for example, between the flange *D* and the main casting, Fig. 122, additional provision is made by laying long wisps of straw between the courses of brick. The service of the straw is similar to that of the hay rope of a barrel core.

Jointing. The joint in loam work is made by a plate lifting away from a loam seat, or by two loam surfaces separating one from another. In forming the first of these the loam seat is swept up and allowed to partially set, then the surface is brushed with oil, and parting sand is thrown over it. The seat should then be soft enough to allow the iron plate to sink into it sufficiently to find a good bearing, while the oil and parting sand will prevent the loam facing from adhering to the underside of the plate. For the loam-to-loam joint, the same method is used, but the loam is allowed to set somewhat harder before building the joint against it. The angle of the main joint should be about 1 in 4 inches.

To insure the different parts being put together for casting in exactly the same position in which they were built, a guide surface of loam is smoothed across the joint at three or four convenient points on the outside walls of the mold. These surfaces are each marked differently with the edge of the trowel, similar to the cut at *C*, Fig. 120.

Drawback. To properly separate and finish some molds, it is necessary to lift away a portion of the mold before lifting the main part. Such a portion is called a *drawback*. The drawback is always built up in position against a pattern or sweep. With the cover plate, which on a smaller scale often serves the same purpose, as at

D, Fig. 122, a flat joint is made on the outer wall of the mold, but the cover plate is swept up separately. At *3*, Fig. 123, is shown a drawback which carries but a few courses of brick. It may be lifted away by lugs cast in the drawback plate with little danger of displacing its brickwork in handling.

If the shape of the drawback renders it impracticable to handle it by the lower plate alone, the brickwork should be bound together by means of hook bolts which clamp on a top plate set sufficiently below the upper joint to be entirely protected from the metal. This upper plate has staples cast in it by which the whole drawback may be lifted. At *B*, Fig. 120, the typical construction of such a piece is illustrated. The drawing shows one-half the length of the brickwork removed to bring out more clearly the rigging used. The upper end of the second lifting staple shows at *a*, with the loam cut neatly away to allow hooking into the staple.

Where the main core lifts away or is to be covered with metal over its top, it must be bound together in a similar manner. This is illustrated in the mold for the marine-engine cylinder, Fig. 123, in which both of these conditions occur.

Example of Internal Flange. If a casting has an internal flange requiring thickness of metal underneath the main core, the rigging will be altered to fit these conditions, as shown at *D*, Fig. 120. In this sketch *a* is a sticker plate and so will carry the loam necessary to face the bottom of the core. To this the small bearing plate *b* is securely bolted by the hook bolt *c*. This plate must set directly upon solid brickwork, as it carries the weight of the entire core. On this bearing plate are cast three studs which firmly support the sticker plate at the required height above the flange surface. The sticker plate carrying this print is filled with loam or dry sand and given a first baking, then swept to a finished surface before being inverted into position. Then the remainder of the core is built up on top and bound together, as in the previous example. Another way to form the bottom of this core is to sweep up a dummy flange *d*, in mud. Set the bearing plate *b*, and work the loam in around the studs to form the short neck to the level of the top of the flange. Then spread over this flange $\frac{1}{2}$ inch of loam and bed down onto this the sticker plate which has been previously filled with loam and dried, as is described below. Be sure that the studs on *b* bring up to a

firm bearing against the plate *a*, then clamp tight with hook bolts and proceed to sweep-up the body of the core.

Bedding Cover Plate. In case a cover plate must be bedded down against a flat surface, as in the example just mentioned, or must take the impression of an irregular surface on the top of a mold or pattern, as illustrated in Fig. 123, the method to pursue is as follows: After casting, invert the plate and carefully lower it into position, and make sure that all fingers clear the surface by at least $\frac{1}{2}$ or $\frac{3}{4}$ inch. Now set the plate with the fingers up, fill in with loam enough to just clear their tops, leaving the proper openings for runners, risers, tie bolts, etc., and dry thoroughly in the oven. Upon removal from the oven, invert and try this loam cover again on the surface it must fit; scrape away any portions which project too much. Now hoist away the cover and coat the face with clay wash. Having previously prepared the surface of the pattern with oil and any loam joint with oil and parting sand, spread an even thickness of fresh loam all over and bed the plate down upon this. The cover plate, being still hot, will, by the aid of the clay wash, cause the thin layer of fresh loam to dry out and stick fast to the dry loam forming the body of the plate.

Simple Mold. As an example of a simple loam mold let us consider the details of a large casting, having the shape of the frustrum of a cone, with a flange at the top and bottom and a flanged nozzle projecting from one side, such as the section clearly shown in Fig. 122.

Foundation. Set the sweep, level up the building plate, and, building the brickwork as shown in *A*, Fig. 120, sweep the seat, joint, and bottom surface of flange, as shown at *A*, Fig. 121. The lower flange may be formed by a wooden pattern furnished by the pattern maker, but it is more common to have the sweep made with the small board *x*, which may be removed. By doing this the exact shape of the flange may be swept up without changing the main sweep, as shown at *B*, Fig. 121. This dummy flange, as it is called, is swept-up from fairly stiff mud.

Cope. The next step is to seat the cope ring and set the cope sweep, as shown at *C*, Fig. 121. This sweep shapes the mold for the outside of the casting, for the top flange, and for the top joint of the mold. Loam is thrown, a handful at a time, against the joint and

dummy flange, and the engaging faces of bricks are rubbed with loam and pressed into position.

When the top of the lower flange is reached in this way, the courses are laid-up for about 2 feet before the loam is spread upon their inner surface and struck off. This method is pursued until the mold is built to its full height.

The projecting nozzle is formed by a wooden pattern; this should be well oiled, and the brickwork and loam laid-up under it to support it at the proper level, as given by the center line on the pattern and corresponding line on the sweep. Such projections frequently must be supported in their exact position with reference to the main pattern by temporary wooden framework or skeleton work until the mold is built up under them.

A finger *y* nailed to the top member of the cope sweep, shapes the guide surfaces on the outside of the mold which are used to center the cover plate in closing the mold. A similar finger exactly the same distance from the spindle, is fastened to the sweep used to form the cover plate.

After the finishing coat of slip has been swept on the surface of the cope, a joint surface about 4 inches wide is struck off flush with the outer face of the nozzle and that pattern is drawn out.

Then the whole cope is lifted off and set on iron supports where it may be conveniently finished with black wash and slicks. It is then baked over night in the oven.

Center Core. The dummy flange is now entirely removed from the first part swept, the core sweep is set, *D*, Fig. 121, and the center core is struck up. This core is then blackened, slicked off, and baked. The cover plate is struck off with the stickers up, and baked so. This cover carries six 1-inch round holes through it, which will be just over the shell of the metal when the mold is closed. Five of them connect with the pouring basin and serve as runners, while the sixth serves as a riser.

Closing. In assembling the mold for pouring, the core is first set on a level bed of sand, the cope is accurately closed over it by the aid of the guide marks, and lastly the cover plate is closed in position. Now the whole mold is firmly clamped by blocking under the spider, from which wrought-iron loops or strings connect under the lugs of the building plate, as shown in Fig. 122.

The small core for the nozzle is now set, resting on stud chaplets. The cover plate *D* is slid over the end of this core and thus holds it firmly in position.

The casing is now placed around the mold and molding sand rammed in to support the bricks against the casting pressure. At the level of the nozzle core cinders are placed, and a pipe leads off to carry away the vent gases. The sand is rammed to about 12 inches over the cover plate and in it are cut the channels connecting the pouring basin and runners. A couple of bricks are set in the bottom of the basin to receive the first fall of metal from the ladle.

Pouring. In pouring, the runners must be flooded at once and kept so until the mold is full.

In heavy cylindrical castings it was formerly thought necessary to carry the shell of the casting some 6 inches higher than the top flange. This head served to collect all dirt and slag that perchance entered the mold with the iron, and it was cut off in the machine shop and returned to the foundry as scrap. With the increased knowledge of iron mixtures this head is now done away with in most instances.

Where a large casting is to finish practically all over, and very clean metal is therefore necessary, overflow channels, connecting with pig beds, are often constructed in modern practice. Then, when pouring, the metal is not stopped until a certain per cent of it has been flowed entirely through the mold. This of course tends to wash out any dirt which may have gotten into the mold when pouring began.

When the casting is cold, the casing and packing sand as well as the blocking under the spider are removed. Then the whole mold is carried to the cleaning shed where the bricks are removed and the casting cleaned.

Intricate Mold. As an example of a complex piece of loam work, let us consider the molding of a modern marine-engine cylinder, as shown in section, Fig. 123. The example given is that of a double-ported low-pressure cylinder of a triple-expansion type. In this case a full wooden pattern should be built, with core boxes for the various dry-sand cores that enter into the construction of the mold.

Foundation. The limits of this article prevent a detailed discussion of this subject; we will, therefore, confine ourselves mainly with

an explanation of the drawing, Fig. 123. The heavy building plate has a spindle opening somewhat to one side of its middle to be under the center of the cylinder. Upon this building plate the foundation of the mold is swept, carrying the seat for the cope ring, the bottom face of the flange, and the seat for the main cylinder core. The cope ring *1* is made wide enough on one side to carry that part of the mold forming the steam chest. The main cylinder core *2*, the construction of which has already been explained, is next swept-up and lifted away, finished, and baked.

Cope. Now the cope ring is seated, and the mold built and struck off for the bottom of the steam chest on a level with the bottom face of flange. Then the pattern may be set. Its position is accurately determined by the main cylinder print and the smaller prints of the steam chest which are bedded into the loam in accordance with measurements along a radial line marked off on the loam surface. With the pattern well oiled, the cope is built to the height of the upper flange of the cylinder; the entire back of the steam-chest core print being left open. The top of the steam chest is lifted off with the drawback *3*, which joints at the middle of the upper steam nozzle, and carries that part of the mold to the level of the main cope joint. The two steam nozzles and the exhaust nozzle may be made with separate cores as explained in *D*, Fig. 122. By using the drawback, the entire top of the chest core print is left open for convenience in setting the chest and port cores.

The top of the cylinder is jacketed, and through it pass the stuffing-box and manhole openings. The flanges of these two openings connect and in the pattern are left loose. The whole top surface is so irregular that it requires three levels of sticker plates to mold it, aside from two small cover plates over flanges.

Covers. To the main cover *4 4 4 4* with its various lengths of fingers, is bolted a crab *5 5 5* to carry the loam below the flanges of the stuffing box and manhole; and below this again are hung the dry-sand cores, *8 8 8*, forming the jacketed part of the cylinder head. On top of the main cover is fastened a separate plate, *6*, to shape the top of the upper steam inlet. And at *7* a plate with wrought-iron bars cast along its edge carries the loam back of the steam-chest flange. The small cover plates, *9* and *10*, allow the flanges to be drawn for the parts which they mold.

The pattern is made in many parts so as to properly draw from the mold. When this has been done, all mold surfaces are carefully blackened and slicked before baking.

Coring. While the mold proper is being built, the dry-sand cores should be made up by the core makers, with the necessary rods, hangers, vent cinders, etc., as described under Core Making.

The manhole core, *11*, is made with a stop-off piece in the box to give the proper angle at the bottom of the core. It is hung to the cover and clears the main core by $\frac{1}{8}$ inch. The stuffing-box core rests in a print in the main cylinder core, and is held by a taper print in the cover plate *10*.

The jacket cores are hung as shown. The openings made in the loam above the crab, to allow the hook bolts to be drawn up tight, are stopped off with green sand as previously described. The inlet cores *12 12*, the exhaust core, *13*, and the lightening cores, *14 14 14*, are all bolted directly through the steam-chest core, *15*, to horizontal bars which are long enough to bear against the sides of the mold at the back. The upper inlet core, *12*, is kept from lifting under the pouring strain by being bolted to the body of the main cylinder core. Stud chaplets are also set between the inlet and exhaust cores to ensure correct thickness of metal at these points.

Venting. The vent is taken off from the main cylinder core through the stuffing-box core at the top. Sometimes a small ladleful of metal is poured through this opening, when the piece is being poured, to ensure lighting these gases. The vent for the series of port cores is taken off by ramming a cinder bed up the entire back of the steam-chest core, allowing the gases to escape at the top. For safety, also, vents are taken from the bottom of the port and chest cores by the usual pipe vent.

Pouring. The provision for pouring this mold requires especial attention. Notice the construction of the main basin, *16*. The long runner *17*, leading to the bottom gate, is left open on one side when the mold is built, so that it may be easily finished and kept free from dirt. Its open side is closed by cover cores when the mold is rammed up.

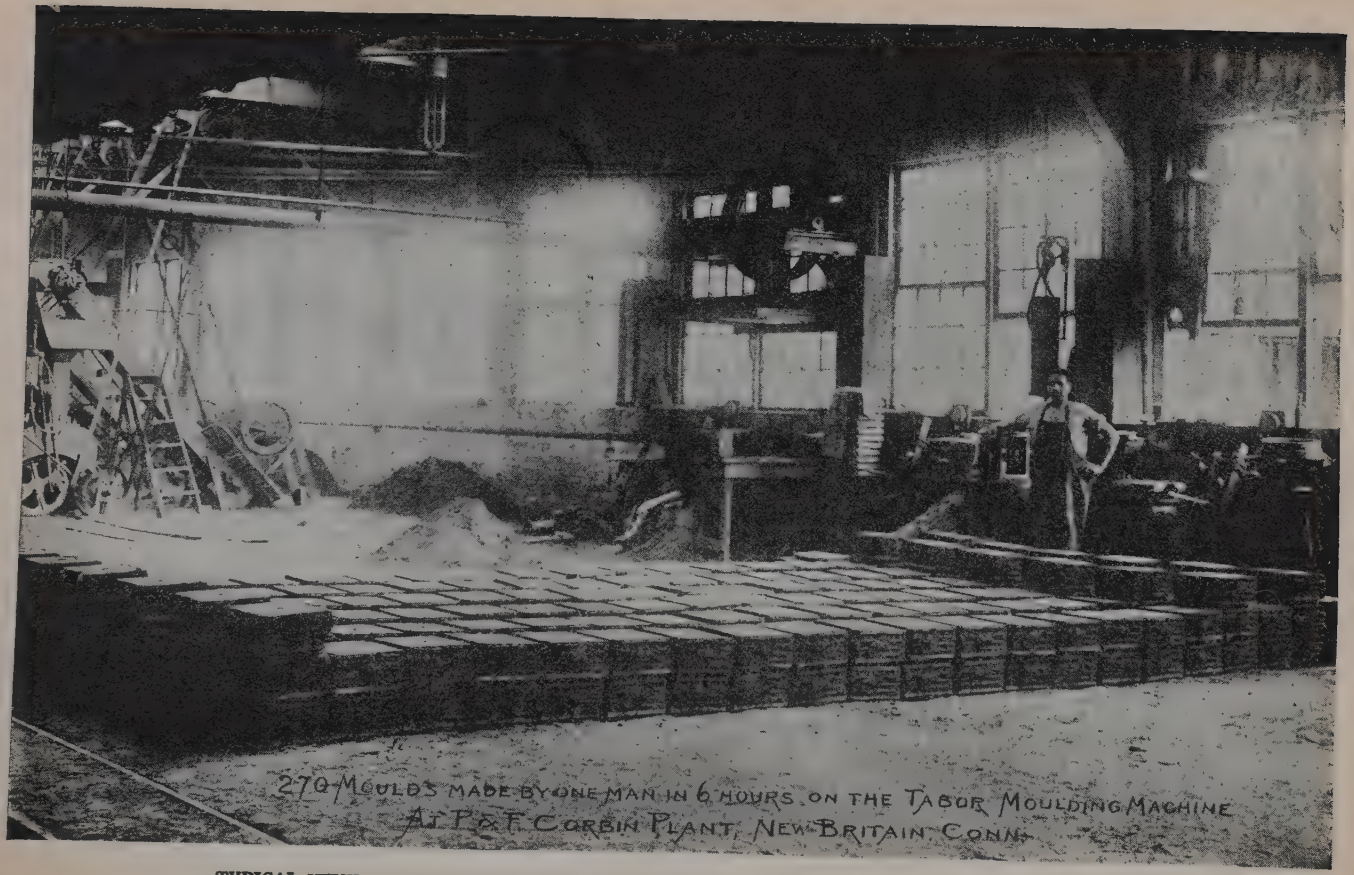
Ten or twelve small gates like *18* are connected with the pouring basin, by semicircular channels, but are so placed that no metal shall fall on a core. With the basin arranged as shown, the

bottom part of the mold is first flooded with iron. When this has been done, the metal is poured in faster, so that hot iron is well distributed around the shell of the casting through the small top gates. Should the mold be poured at first from these top gates, the fall of the iron through the full height of the cylinder to the lower flange might result in cutting the loam on that surface.

Molds of this size are usually rammed in a pit so as to bring the pouring basin conveniently near the floor. The portion above the floor level is, of course, rammed inside a casing, as described in the previous example.

To guard against uneven cooling strains in this intricate casting, the clamping pressure on the mold is relieved when the metal has solidified, but the sand is not removed from around the brickwork for several days. This allows very gradual even cooling.

It will be noticed that the piston does not work directly upon the inner walls of this type of cylinder. A separate hollow shell or lining is cast of strong tough iron. This has outside annular ribs at top and bottom and middle, which are turned to fit correspondingly projecting ribs seen on the inside of the casting just under consideration. An air space is thus left between the lining and main casting which forms a jacket around the bore of the cylinder.



TYPICAL VIEW OF FOUNDRY WITH MOLDS MADE BY POWER SQUEEZER READY TO POUR

Courtesy of Tabor Manufacturing Company, Philadelphia, Pennsylvania

FOUNDRY WORK

PART II

CASTING OPERATIONS

MELTING

General Characteristics. The subject of melting the metal which is to be poured into molds is one of the most important considerations in the foundry. It is also one which has received much attention in the last few years, the endeavor being to get away from the old rule-of-thumb methods and to arrive in the iron foundry at something near the precision in resulting metal that is already attained in the brass shops or the steel foundry.

The heat for all melting is obtained from practically the same two chemical elements—carbon, and oxygen—carbon coming from the fuel, be it coal, coke, oil, or gas; and oxygen coming from the air of the blast.

The design of the furnace, the kind of fuel used, and the application of the blast vary in accordance with the peculiar properties of the different metals and the degree of heat required to melt them.

The melting of steel, copper alloys, and malleable cast iron will be dealt with under separate headings. We shall now consider only the melting of gray foundry irons.

CUPOLA FURNACE

Furnace Parts. Foundry iron is melted in direct contact with the fuel in a cupola furnace. The name was derived from the resemblance of the furnace to the cupola formerly very common on the top of dwelling houses.

Bottom. The cupola consists of a circular shell of boiler plate, lined with a double thickness of fire brick and resting on a square bedplate, with a central opening the size of the inside of the lining. This bottom is supported some $3\frac{1}{2}$ feet above a solid foundation, on four cast-iron legs. The bottom opening may be closed by cast-iron doors, which swing up into position, and are held so by an upright

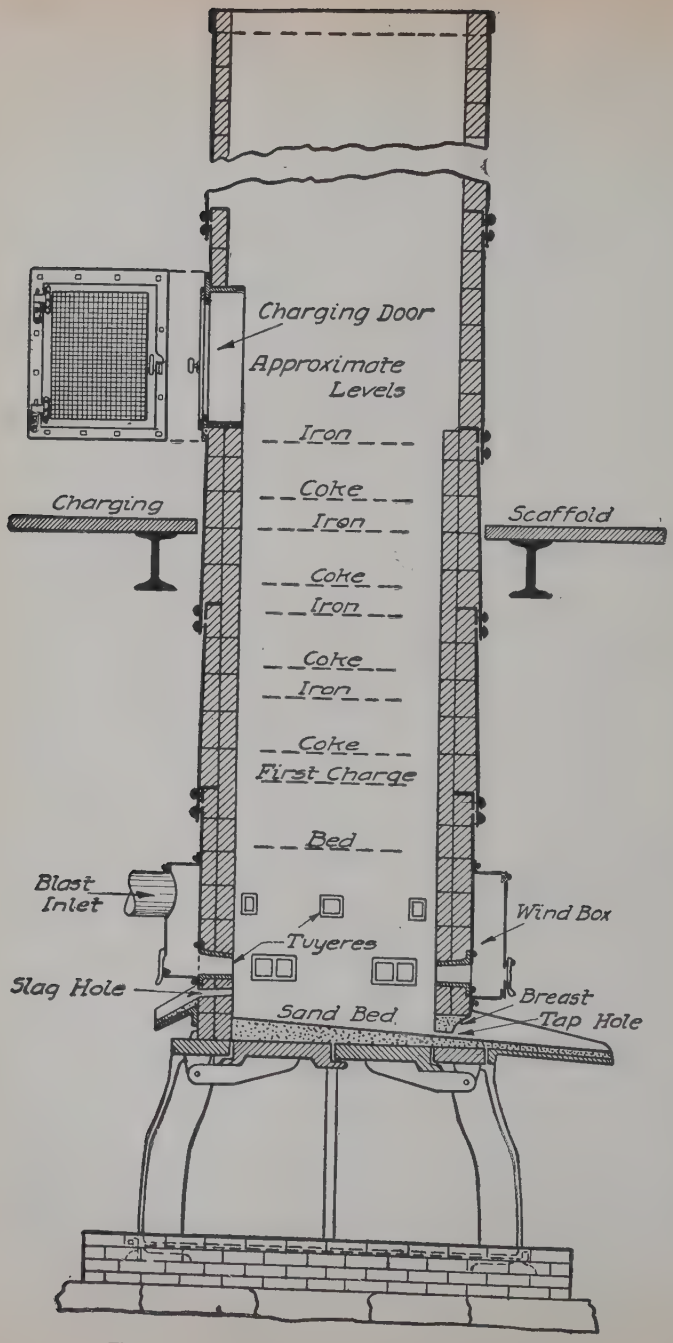


Fig. 124. Section Through Modern Cupola Furnace

iron bar placed centrally under them. These doors, protected by a sand bed, support the charge during the heat, and drop it out of the furnace when all the iron has been melted. The legs curve outward and the doors are hinged as far back as possible to protect them as much as can be from the heat of this "drop".

Breast. At one side, level with the bottom, is the breast opening, at which place the fire is lighted, and in which the tap hole is formed for drawing off the melted metal. The spout, protected by a fire-sand mixture, projects in front of the breast and guides the metal into the ladles.

Slag Hole. On cupolas over 36 inches inside of the lining, a slag hole is provided, which is similar to the tap hole, and is placed opposite the spout and about 2 inches lower than the main tuyères. Fig. 124 shows a section through a modern cupola furnace, and needs but little further explanation.

Lining. In lining the stack, the layer next the shell is usually made of boiler-arch brick about the size of regular fire brick. These are set on end, and should be fitted as tightly together as possible, and laid in a thin fire cement, made of very refractory fire clay and fine sharp silica sand. The object is to fill every crevice with a highly refractory material. Specially made curved fire brick can be purchased for the inside lining, although some foundrymen use the arch brick for this lining as well. The lining over the tuyères is shaped to overhang them slightly, to prevent melted slag dropping into them during the heat. The lining burns out quickest about 22 inches above the tuyères, at what is practically the melting zone. The angle shelves riveted to the shell, as seen in the illustration, allow this section of the lining to be renewed without disturbing the rest of the stack.

Tuyères. The oblong air inlets, called tuyères, are placed about 12 inches above the bed, and connect with an air-tight wind box which surrounds the outside of the stack near the base. The tuyères direct the blast into the fuel, increasing the heat sufficiently to melt the charge. In the wind box, opposite each tuyère, is an air-tight sliding gate with a peephole, which allows the melter to look directly into the furnace.

In the larger cupolas a second set of tuyères is arranged about 10 inches above the main ones. They are used, when long heats are

TABLE III

Sizes of Cupola Furnaces

Diameter Inside of Lining (inches)	Cupola Height (feet)	Charging Door Size (inches)	Melting Capacity	
			Per Hour (tons)	Per Heat (tons)
18	6 to 7	15 by 18	¼ to ¾	1 to 2
20	7 to 8	18 by 20	½ to 1	2 to 3
24	8 to 9	20 by 24	1 to 2	3 to 5
30	9 to 12	24 by 24	2 to 5	4 to 10
40	12 to 15	30 by 36	4 to 8	8 to 20
50	15 to 18	30 by 40	6 to 14	15 to 40
60	16 to 20	30 by 45	8 to 16	25 to 60

run off, to make up for loss of wind caused by the main tuyères becoming partially choked by slag.

The height of the tuyères above the bed varies with the class of work to be poured. Where the metal is tapped and kept running continuously and is taken away by hand ladles, as in stove-plate work, the tuyères are as low as 8 inches or 10 inches above the bed; while in shops where several tons of metal may be required to fill one mold, the tuyères are as high as 18 inches above the bed. The height of the spout above the molding floor also varies in the same way; for hand-ladle work it may be but 18 inches above the floor, while a height of 5 or 6 feet may be required to serve the largest crane ladles.

Charging. Several feet above the bottom, there is a door in the side of the stack, through which the stock is charged into the furnace. A platform or scaffold is constructed at a convenient level below the charging door, and all stock is charged into the cupola from this platform. It should be at least large enough to store the stock for the first two charges of fuel and iron.

Table III, prepared by Dr. Edwin Kirk, gives the approximate height and size of charging door and the practical melting capacity of cupolas of different diameters.

Blast. *Fan Blower.* Blast for the cupola is furnished by either a fan blower or a pressure blower. Fig. 125 shows a modern fan blower, of which the blast wheel is detailed at *A*. The high speed of the blades forces the air, by centrifugal action, away from the center of the shaft. The casing is so designed that the blades cut

TABLE IV

Fan-Blower Performance

Fan Diameter (inches)	Speed (revolutions per minute)	Wind Pressure (ounces per square inch)
18	4100	5
24	3750	6
36	2900	10
48	2600	14

off, as it were, at the top of the main outlet, the air being thus forced through the blast pipe. The current of air is continually being drawn into the fan through the central opening around the shaft.

Since air is very elastic, and the pressure in this case depends entirely upon the centrifugal action of the blades, should the tuyères

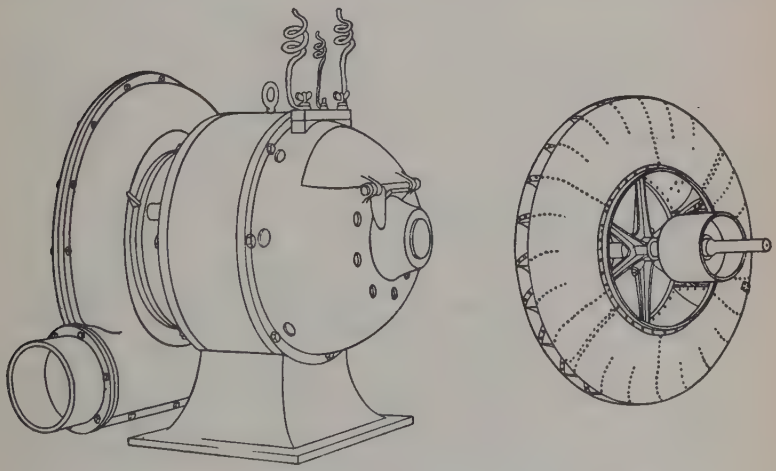


Fig. 125. Typical Fan Blower

become clogged, the amount of air forced into the furnace will be reduced proportionately. On the other hand, it requires less power to operate the fan with reduced area of outlet than it does when the discharge is open free.

An idea of the speeds at which blowers should run may be obtained from Table IV.

Pressure Blower. In the pressure blower shown in Fig. 126, the action is positive, as will be seen from the sectional view *A*,

Fig. 126. The wipers mesh into each other in such a way that they entrap a quantity of air and force it out of the opening.

The full quantity of air is therefore forced through the tuyères at all times. In such case, the power necessary to operate the blower increases as the tuyères become choked, and the excessive force of the blast, due to choked tuyères, is hard on the lining of the cupola.

Gage. The cupola should have a blast gage attached to the wind box to measure the pressure of air which enters the tuyères. The

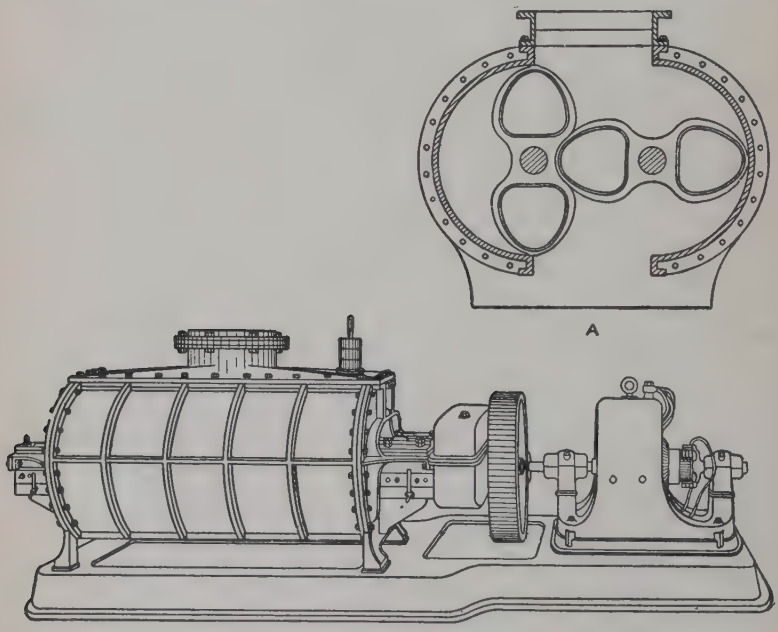


Fig. 126. Motor-Driven Pressure Blower

pressure should be sufficient to force the air into the middle of the cupola to insure complete combustion. The unit of air pressure is 1 ounce. From 8 to 16 ounces is approximately the range usual in cupolas of from 48 inches to 70 inches diameter, inside lining.

This pressure is measured by the displacement of water or mercury in a U-shaped tube. With both legs of the tube the same size, as in *A*, Fig. 127, the graduations represent the pressure of double that height of liquid. Such graduations would be as follows:

With a water gage, a difference in levels of 1.73 inches corresponds to 1 ounce wind pressure, so that the scale graduations per ounce would be spaced

$$\frac{1.735}{2} = .865 = \frac{55}{64} = \frac{7}{8} \text{ in.} - \frac{1}{64} \text{ in.}$$

With mercury, a difference in levels of 0.127 inch corresponds to a pressure of 1 ounce so that the scale graduations would be spaced

$$\frac{0.127}{2} = .0635 \text{ in.} = \frac{1}{16} \text{ in.}$$

As this last spacing would be too small for practical use, mercury gages, as at *B*, Fig. 127, are made with an increased area exposed to the blast pressure, and are graduated accordingly.

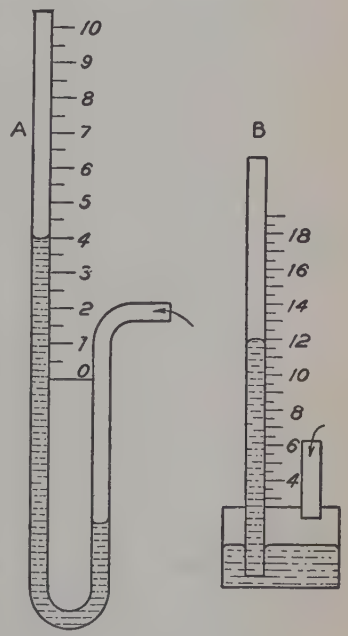


Fig. 127. Wind Gages

Principles of Melting. Combustion cannot take place without oxygen, of which the air is the most abundant source of supply. For example, in the incandescent electric light, a strip of carbon is heated to a white heat, but it does not consume, or burn up, because all air has been exhausted from within the globe.

In the cupola furnace, both coal and coke are used as fuel. They consist largely of carbon, and, after being lighted by the kindlings, are kept at a glowing red heat by the natural draft through the open tuyères. The blast supplies the oxygen necessary for a melting heat. The quantity of air forced in by the blast cannot be entirely taken up by the layers of fuel immediately above the tuyères; thus, complete combustion does not take place until a distance of 18 to 23 inches above the tuyères is reached. This is termed the *melting zone*. It is the aim of the melter to keep the top of his bed as nearly as possible at this level, so that the iron resting on it shall be exposed to this intense heat and melt rapidly. As the fuel of

the bed burns away, this level tends to be lowered. But the iron on top of it melts and drops to the bottom of the cupola; and the subsequent charge of coke restores the level of the bed for the next charge of iron; and so on.

Cupola Operation

Running a Heat. The following routine must be pursued each time a heat is run off in the cupola:

(1) *Clear away* the dump from the former heat.

(2) *Chip out* the inside of the furnace with a special hand pick, removing the lumps of slag which collect about the lower part of the cupola walls, especially above the tuyères. Where the slag coating is comparatively smooth, do not touch it, as that is the best coating possible for the lining.

(3) *Daub up* with a mixture of fire sand, held together with about 1:4 fire clay, and, wet with clay, wash to a consistency of thick mortar. Smear the surface to be repaired with clay wash; then, using the hands, plaster the daubing mixture into the broken spots in the lining, being careful to rub it in well, especially about the tuyères. The top of the tuyères should be kept slightly overhanging.

The greater part of the daubing will be required from the bottom to the level of melting zone, about 22 inches above tuyères.

(4) *Swing up* the bottom doors, and support them by a prop of gas pipe.

(5) *Build the bottom;* first cover the doors with a 1-inch layer of gangway sand or fine cinders; then ram in burnt sand tempered about the same as for molds. This must be rammed evenly all over the bottom, and especially firm around the edges. The bottom should be made flat and level from side to side, with only a slight rise around the lining which should not extend more than 1 or 2 inches from the lining. The pitch varies with size of cupola; 1 inch to the foot will answer for cupolas of 24 inches to 30 inches diameter inside lining, while one-half that pitch will do for the larger furnaces.

The cupola bottom should be able to vent so that it will dry out quickly, and not cause the metal to boil before the furnace is tapped. It should be strong enough to hold its surface during the heat, but to break and drop at once when the bottom is dropped. Too much pitch causes excess of pressure on the bott, making trouble in botting

up; with too little pitch the metal will not drain well, causing a tendency to chill at the tap hole. A little daubing mixture should be worked into the sand bottom just inside the tap hole, to prevent breaking at this point when the tapping bar is forced through.

(6) *Lay the fire* with shavings first, just inside the breast; then with fine kindling; then with enough large kindling to make sure of lighting a layer of coke sufficient to form the bed. When the gases from the lower part of the bed burn up through, showing that the fuel is well lighted, level up the bed with the addition of a little more coke.

(7) *The first charge* of iron should be put on now. Follow this with alternate charges of fuel and iron, to the level of charging door.

(8) *Form the tap hole;* lay a bar of iron about $\frac{7}{8}$ inch round in the spout, projecting in through the breast opening; fill in the breast around the bar with a strong loamy molding sand rammed hard. Recess this in well to leave the actual tap hole as short as possible.

(9) *Put on the blast* when ready for the metal, and leave the tap hole open. Bott up when the metal begins to run freely—generally about 7 minutes after blast is on.

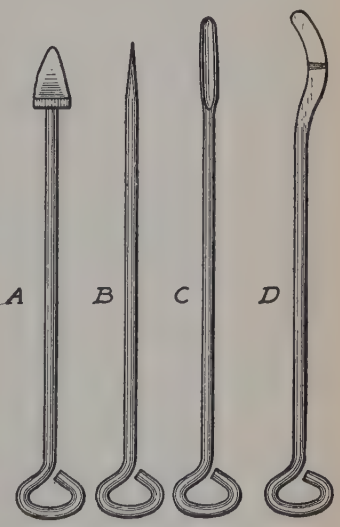


Fig. 128. Tapping Bars

Bott clay should be mixed with about $\frac{1}{8}$ sawdust, to make it more fragile when tapping, and is made up in small balls, and shaped onto the end of the bott stick *A*, Fig. 128.

(10) *Tap* when sufficient metal has collected to supply the first ladles.

The tapping bar *B*, Fig. 128, has simply a round taper point; *C* is a gouge or spoon-shape, useful for trimming sides of hole if the bott does not entirely free itself when tapped.

(11) *Drop the bottom*, when all the iron has been melted and run off. This is done by pulling away the bar that supports the bottom

TABLE V

Foundry-Ladle Data

	Hand Ladle		Bull Ladle		Crane Ladle		Geared Ladle	
Illustration	Fig. 129 *A*		Fig. 129 *B*, *C*		Like *C*, with bail		Fig. 130	
Control	Hand shank		Single or double hand shank		Bail with single or double hand shank		Worm gear on heavy bail	
Capacity (pounds)	30 50		80 350		300 2,000		1,000 35,000	
Weight (pounds)	15 16		35 100		115 350		1,900 7,000	
Dimensions (inches)	Inside Shell	Lining Thick-ness	Inside Shell	Lining Thick-ness	Inside Shell	Lining Thick-ness	Inside Shell	Lining Thick-ness
Top	7 to 8	$\frac{3}{4}$	9 to 15	$1\frac{1}{4}$	14 to 26	$1\frac{3}{4}$	20 to 75	2 to 4
Side	7 to 8	$\frac{1}{2}$	9 to 15	$\frac{1}{2}$ to $\frac{5}{8}$	14 to 26	$\frac{5}{8}$ to 1	20 to 60	1 to $4\frac{1}{2}$
Bottom	6 to 7	$\frac{1}{2}$ to $\frac{3}{4}$	8 to 13	$\frac{3}{4}$ to 1	12 to 23	1 to 3	18 to 66	$1\frac{1}{2}$ to

doors. Throw water on the dump by bucket or hose, to deaden the heat, and leave it to cool off over night.

Foundry Ladles. As the melted metal flows from the spout of the cupola, it is caught in ladles. The sizes of these are designated by the weight of metal they will hold; they vary from 30 pounds to 20 tons capacity.

Table V, containing references to Figs. 129 and 130, give compact data regarding foundry ladles.

The names of ladles relate to the method of carrying them. Hand ladles are made of cast iron or pressed steel. The larger ladles are built up of boiler plate. Cast iron is poured from the top of the ladle, which should therefore be provided with lips.

Lining. Ladles must be lined to protect them from burning through. Up to 1-ton capacity, the cupola daubing mixture is used. The bowl is smeared with thick clay wash, and the clay pressed in hard with the hands, being rubbed smooth on the inside. The lining should be kept as thin as possible, $\frac{5}{8}$ to $\frac{3}{4}$ inch on hand ladles, 1 inch to $1\frac{1}{2}$ inches on large ones; the bottom lining being from

one-third to one-half thicker than sides, as it receives the first fall of the incoming metal.

The larger ladles are first lined with fire brick of thickness proportionate to their size, and then daubed on the inside with clay mixture similar to cupola lining. The lining must be well dried before use, to drive out moisture. In stove-plate and hardware shops, where most of the pouring is done with hand ladles, a special ladle drying stove similar to a shallow core oven is provided. A wood fire is built inside of the larger ladles to dry them out. To preserve a lining as long as possible, slight breaks are repaired daily. As with the cupola, the slag formed by the hot metal forms the best coating possible for the inside lining.

Pouring. The first thing to be considered in connection with pouring is skimming off the slag which collects on top of the metal. This should be done on the larger ladles before leaving cupola, and again while metal is being poured. For this, a long iron rod is used, with blade shaped as in *D*, Fig. 128. This is rested across the top of the ladle near the lip, and effectively holds the slag back; the long handle permits the skimmer to stand well back from the heat of the metal. On small ladles, skimmers are of course shorter, and the end is bent up more, for convenience, as the ladles will be much nearer the floor when pouring with them.

Fig. 129. Hand and Bull Ladles

Hand and bull ladles are shown in Fig. 129, while Fig. 130 shows a crane ladle.

General Precautions. Much skill is required in pouring a mold. A molder must know the character of the work, and judge whether it must be poured fast or slowly. In general, light work cannot be poured too fast. Heavier work is poured more slowly. Care must be exercised to keep the stream steady from the first, and not to spill into the mold, as this may cause cold-shuts or leave shot iron in the castings. The runner basin must be kept full, for gates and runners are made with this express purpose in view, as has been stated previously.

Metal must not be allowed to chill or freeze in the ladle, as this would destroy the lining when it came to removing the cold metal. Metal left in the ladles when the mold is full, must be poured back into a larger ladle or emptied into a convenient pig bed. These latter are built in a sand bed usually near the cupola; or stout cast-iron pig troughs or chills are provided. The chills should taper well on the inside, holding about 60 pounds each. Some are arranged to swing on trunnions for convenience in dumping. They should be smeared with a heavy oil and dusted with graphite, to prevent the metal sticking in them. It is safer to heat these pig molds as well, so that no moisture will form and cause a kick or explosion when hot metal is first poured into them.

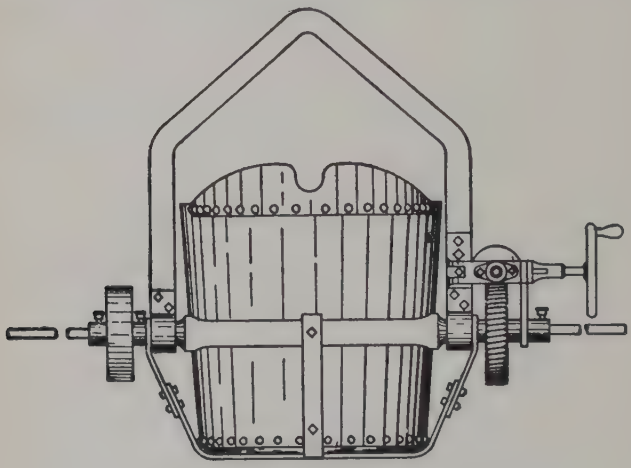


Fig. 130. Crane Ladle

Cupola Mixtures

Requirements. By the term *cupola mixture* is meant the proportioning of the various pig irons and the scrap that make up cupola charges, with the object of obtaining definite physical and chemical properties in the resulting castings.

The requirements of castings vary; and metal that would be good if run into thin stove plate, would be entirely too soft for heavy machine castings. Again, iron that might answer all requirements of a bed plate would not be strong and tough enough for steam-cylinder

work. The one in charge of this work, therefore, must so mix the different irons that his castings shall be soft enough to machine well if necessary, and at the same time be hard enough to stand the wear and tear of use.

Precision Essential. Formerly the appearance of the fracture of a pig or of scrap was the sole guide in determining mixtures. Unquestionably the fracture of iron indicates to the experienced eye much as to its physical properties, but this method of mixing has repeatedly proved misleading.

Representative practice today recognizes chemical analysis of the various irons as most essential to the proper mixing. Many firms now buy their pig iron and many other allied supplies by specification; and the chemical analysis of the iron must show that its various metalloids come within certain limited per cents.

To understand, then, these modern methods, we must consider the subject of the chemistry of iron.

Affecting Elements. By the chemical definition, an element is a form of matter which cannot be decomposed, or, in other words, cannot be broken up into other forms by any means known to science.

Iron is such an element; but absolutely pure iron is of no commercial value; it is only when it is combined with impurities—or, as we must recognize them, other chemical elements—that mankind is interested in it.

In the forms of iron with which we are dealing—pig iron, and cast iron—five elements are considered as affecting their physical properties. These elements are carbon, silicon, sulphur, phosphorus, and manganese.

Carbon. Carbon is the most important and most abundant of all the chemical elements. It forms the principal part of many substances in daily use about us, such as coal, coke, lead pencils, graphite facings, etc.

In its relation to iron, carbon is peculiar in that it occurs in iron in two forms. One is in a chemical combination forming a hard substance with a fine grain, of which tool steel is the purest type. The other is simply a mechanical mixture forming minute facets of free carbon interposed between the crystals of the combined form. It softens cast iron, but weakens it by causing larger crystals to form. In drawing the finger across a freshly cut surface or fracture of cast

iron, some of this free carbon may be rubbed off, and shows as dirt on the finger. We shall use the term *graphite* in referring to this form of free carbon, and the term *combined carbon* in referring to the element in its combined state.

Silicon. Silicon, of itself, is a hardening element in cast iron, but on account of its marked influence upon carbon formations, it is usually considered a softener. During the cooling process, silicon retards the formation of combined carbon, thus increasing the formation of graphite in proportion to the increase of silicon. At the same time, through its own influence on iron, it preserves the fine character of the grain, and so maintains the strength of the casting. In other words, within certain limits, the addition of silicon softens castings without impairing their strength. It makes iron run more fluid, and reduces shrinkage. Silicon varies in castings from 1.50 to 2.50 per cent.

Sulphur. Sulphur is the most injurious element in iron. It makes castings hard, red-short, and tends to the formation of blowholes. At the melting temperature, iron absorbs sulphur from the fuel—a decided reason why foundry coke should be as free as possible from this element. Sulphur in castings should not exceed 0.07 per cent.

Phosphorus. Phosphorus tends to make iron run very fluid when melted. It is a hardener. For machine castings it should not exceed 1 per cent.

Manganese. Manganese strengthens, and, of itself, hardens iron. Chemists are beginning to consider its proportions more carefully, in the belief that under certain conditions it acts as does silicon, softening the castings while retaining their strength. It is usual to keep it below 0.50 per cent.

Factors of Quality. The strength of a casting and the finish which it is capable of taking are largely dependent upon its having a fine even grain. We have seen that the porportions between the combined carbon, the graphite, and the silicon have decided influence upon this condition. But the rate of cooling must also be taken into account. A thin casting cools rapidly, tends to increase the combined carbon, and, without the influence of silicon, would be hard and brittle. In a heavy casting, the metal stays liquid longer, more graphite is thrown off, and the casting is naturally softer. There-

fore light work requires a larger proportion of silicon to counteract the effect of the rapid cooling than does larger work.

Chemical Analysis. Modern practice makes daily analysis for the two carbons, for the silicon, and the sulphur, occasionally testing for the other elements to see that they are kept within their safe limits. Silicon, however, is used as the guide for regulating mixtures.

Proportions of Silicon. The following shows good proportions of silicon for different classes of work:

Casting	Silicon (per cent)
Steam cylinders	1.70
Medium heavy work ($\frac{1}{2}$-inch to 2-inch thickness)	2.00
Light work (less than $\frac{1}{2}$-inch thickness)	2.50

A more complete analysis of results to be aimed for is:

Casting	Elements (per cent)			
	Silicon	Phosphorus	Sulphur	Manganese
Automobile cylinders	2.25	1.0	0.075	0.5
Corliss engine cylinders ($1\frac{1}{4}$- to $1\frac{1}{2}$-inch thickness)	1.20 to 1.70	below 0.1	below 0.095	0.5

To calculate for any result, we must first know the analysis of the irons to be used in making the charge. We shall consider silicon as the guide.

In keeping track of results, the proportion of silicon in the local scrap of an establishment can be accurately estimated. With miscellaneous machinery scrap, this is more difficult; the following, however, are safe estimates:

Casting	Silicon (per cent)
Small thin scrap	2.0 to 2.4
Large scrap ranges	1.50 to 2.0

Method. The analysis of pig iron is made from drillings taken from a fresh fracture. Between the very fine grain about the chilled sides of the pig and the very coarse grain in the center, average-sized

crystals will be noticed in the fracture. It is here that the drillings for analysis should be made, as indicated in Fig. 131. About a $\frac{3}{4}$-inch flat drill is best to use, as it cuts a more uniform chip from the varying grades of pig than does a twist drill.

To determine the analysis of a carload lot of pig iron, the following method is employed: Select ten pigs which will represent an average of the close, medium, and coarse-grained iron in the car. These pigs should be broken, and drillings taken from the fresh fracture. The drillings from these ten fractures are thoroughly mixed together, and about 2 ounces by weight, or a large tablespoonful by measure, is sufficient for the chemical analysis. The result is taken as the average analysis of the carload.

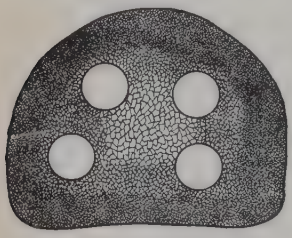


Fig. 131. Section of Pig Drilled for Analysis

The smaller foundries who do not employ a chemist can get a good working analysis of their iron from the furnace from which it is bought. Or, in many cases, sample drillings are sent to a practicing chemist.

Usual Silicon and Sulphur. The proportions of silicon and sulphur contained in the ordinary grades of pig iron are approximately as follows:

Grade of Pig	Silicon (per cent)	Sulphur (per cent)
Ferrosilicon	7 to 12	0.03
Silvery	3 to 5	0.03
No. 1 foundry	2.50 to 2.90	0.03
No. 2 foundry	1.95 to 2.40	0.04
No. 3 foundry	1.40 to 1.90	0.05

Calculation of Mixture. When we have the analysis of our iron, we can proceed to calculate the mixture, bearing in mind that some of the silicon will be burned out of the iron during the heat. From 0.15 to 0.25 per cent is a fair estimate for this loss in cupolas ranging in size from 36 inches to 72 inches inside lining. This loss must be deducted from the final estimate.

Illustrative Examples. It is proposed to make a mixture for miscellaneous machinery castings which require about 2 per cent

of silicon, and we wish to use one-half scrap and three other irons, whose silicon contents are as follows:

Grade of Iron	Silicon (per cent)
Silvery	4
No. 1 foundry	2.65
No. 2 foundry	2.22
No. 3 foundry	1.75
Scrap	2.00

The student should bear in mind that per cent means $\frac{1}{100}$ or .01. To multiply a whole number by per cent, set the decimal point two places to the left in the percentage; thus 35 per cent of 5,000 = .35 × 5,000 = 1,750. In multiplying per cent by per cent, set decimal points in the percentages one place to the left before multiplying, and the result is expressed as per cent; thus 25% of 35% = 2.5 × 3.5 = 8.75 per cent.

Then we may have the following proportions of silicon, using the above irons:

(*A*)	(*B*) (*C*) (*D*)
No. 1	25% × 2.65% = 0.6625%
No. 2	20% × 2.22% = 0.4440%
No. 3	5% × 1.75% = 0.0875%
Scrap	50% × 2.00% = 1.0000%
Total silicon content	= 2.194 %
Deduct for loss in heat	= 0.20 %
Estimated silicon in result	= 1.994 %

Or, with No. 2 and silvery irons, we may have:

(*A*)	(*B*) (*C*) (*D*)
No. 2	45% × 2.22% = 0.999 %
Silvery	5% × 4.00% = 0.200 %
Scrap	50% × 2.00% = 1.000 %
Total silicon content	= 2.199 %
Deduct for loss in heat	= 0.17 %
Estimated silicon in result	= 2.029 %

In these examples, column (*A*) is the kind of iron; (*B*), per cent of this iron used in charge; (*C*), per cent of silicon in single grade of iron; (*D*), per cent of silicon to whole charge as supplied by each grade. One or more per cents in column (*B*) are usually

decided upon before beginning calculations, and then the others are varied until the desired silicon content is obtained.

With this as a guide, it is a simple matter to find the actual weight for each grade, to make up any size of charge. For example, we wish to put 5,000 pounds on the bed and 3,000 pounds on other charges. Then, using the first mixture and the ratio 5:3 between the bed and the other charges, we have:

From column (*B*)	Bed	Other charges
No. 1	25%×5,000=1,250 lb.	750 lb.
No. 2	20%×5,000=1,000 lb.	600 lb.
No. 3	5%×5,000= 250 lb.	150 lb.
Scrap	50%×5,000=2,500 lb.	1,500 lb.
Total iron	5,000 lb.	3,000 lb.

Fuel. Both anthracite coal and foundry coke are used in the cupola. Coal, owing to its density, carries a heavier load than coke, but it requires greater blast pressure and does not melt as fast as coke.

Foundry Coke. Coke, for foundry use, should be what is known as "72-hour" coke, as free as possible from dust and cinders. Coke is made up of a sponge-like coke structure which is almost pure fixed carbon, and an open cellular structure, which makes it especially valuable as a furnace fuel because it is so readily penetrated by the blast.

A representative analysis of a strong 72-hour coke is as follows:

Item	Proportion (per cent)
Moisture	0.49
Volatile matter	1.31
Fixed carbon	87.46
Sulphur	0.72
Ash	10.02
Cellular structure	50.04
Coke structure	49.96
Heat units per pound	12,937 B.t.u.
Specific gravity	1.89

Proportions of Charge. The proportions of the bed fuel, the first charge of iron, and the subsequent charges of fuel and iron vary

greatly with the size and design of the cupola, the grade of fuel used, and the method of charging. To determine the right amount of fuel for the bed, the most practical thing to do is to cut and try, especially with a new equipment.

For 36- to 48-inch cupolas, averaging 22 inches above the tuyères for the melting zone, with a 10-ounce blast to start, the best way to proceed is to chalk off this distance inside the cupola before daubing up. Then, from a $\frac{1}{2}$-inch rod of iron, bend a shape like Fig. 132. The distance *a* equals the distance from the mark inside the cupola to about 4 inches above the bottom of the charging door. When the coke is well lighted, before charging the iron, level off the bed according to this gage. The safe practice is to have the bed too high. If the bed is too high, it is indicated by slow but hot metal; if the bed is too low, the metal is dull. After the first heat, the height may be adjusted until proper melting is obtained; then try always to work to the same height.

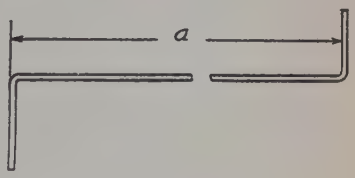


Fig. 132. Bed Gage

The weight and character of the coke charged on the bed should be carefully noted. The first charge of metal should be in the proportions of 2 pounds of metal to 1 of fuel; all others in the ratio of 10 of metal to 1 of fuel. Intermediate charges of coke should be just sufficient to preserve the upper level of the bed. The layer is usually about 6 inches thick; its weight should be carefully taken.

The action of the furnace must be carefully watched, with the object of making it melt the iron charged as rapidly as possible and of bringing it down white hot. Also, the ratio of iron to fuel should be reduced as low as may be, without sacrificing either of these other objects.

Supplementary Operations

Sand Mixing. When a mold is poured, the intense heat of the iron burns out those properties in the sand which give it its bond, making it necessary that a certain proportion of new sand shall be mixed with the heap sand and used as facing, as has been explained in earlier paragraphs.

The facing sand should be mixed daily for the molders by one or more of the laborers, at a place convenient to the storage sheds

and molding floors. A hard smooth floor of clay or of iron plates is a great advantage.

The proportions of the different sands are measured by the shovelful, bucketful, or barrowful, and the sands are spread over each other in flat layers, sufficient water being sprinkled on to temper the pile. The sand then is cut through once with the shovel, is put through a No. 2 sieve, all lumps being broken up, and the refuse thrown

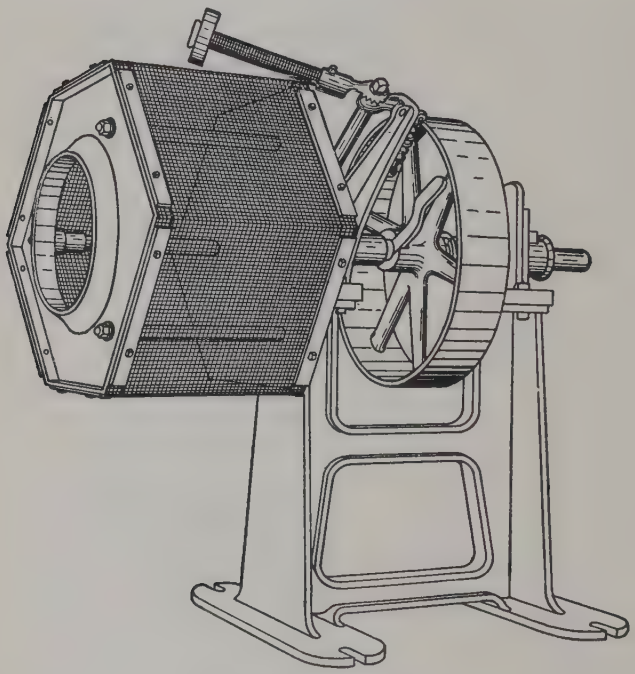


Fig. 133. Rotary Sieve

out is put through a No. 4 sieve, and finally is thrown in a pile ready for use.

When this work is done by hand, the ordinary screen sieve commonly employed by masons is used for the riddling, and a round foundry riddle for the final sifting. To reduce the labor of this, the riddle is slid back and forth on a pair of parallel bars supported conveniently above the storage pile.

Mixing Machines. The two classes of labor-saving machines used in mixing facings, core sand, etc., are those which mix by

riddling; and those which mix by a combined breaking and stirring action. There are many varieties on the market, the illustrations shown being typical.

The rotary sieve shown in Fig. 133 is made with wire screen on the revolving sides, and is driven by belt or connected motor. Sand shoveled into the central opening is sifted in a pile on the floor, or directly into a barrow. The rubber hammer on top automatically raps each face of the sieve as it revolves, knocking the meshes free of sand.

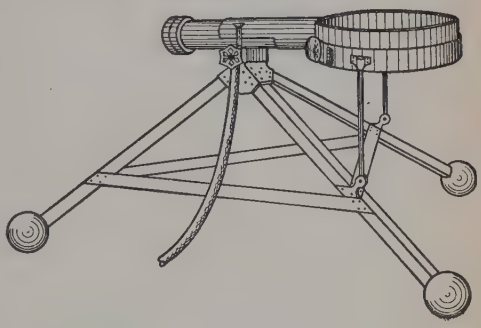


Fig. 134. Sand Shaker

Fig. 134 shows one of the latest labor savers in this line. Here a foundry riddle is supported in a metal ring attached to the piston of the machine. It is made to vibrate rapidly by means of com-

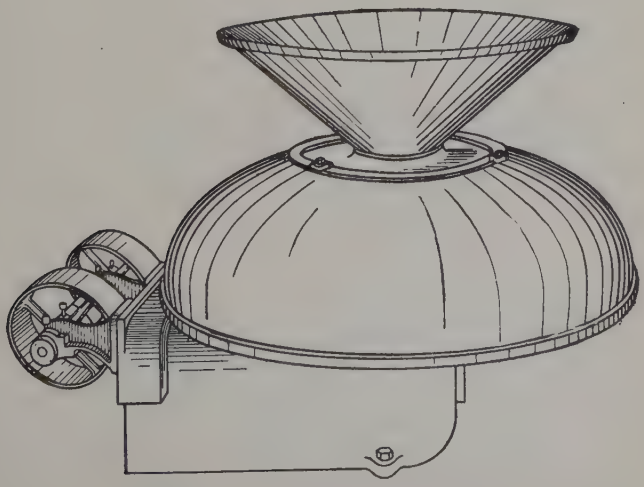


Fig. 135. Pulley-Driven Centrifugal Mixer

pressed air or steam. These shakers are made with portable tripod, as shown; they are also made stationary or are fastened on a post

by means of a swivel joint, to be swung over a wheelbarrow or over a molding machine, and out of the way again when not in use.

Fig. 135 shows a centrifugal mixer. Inside of the umbrella casing, a horizontal plate about 12 inches in diameter and carrying a number of vertical steel pins about 6 inches long is fastened to the top of a short upright shaft driven by a belt running inside of the casing shown at the base of the machine. The machine runs about 1,500 revolutions per minute; and sand shoveled into the hopper is very evenly broken up by the pins and thrown against the steel hood, breaking and shattering any lumps of clay or loam and making a

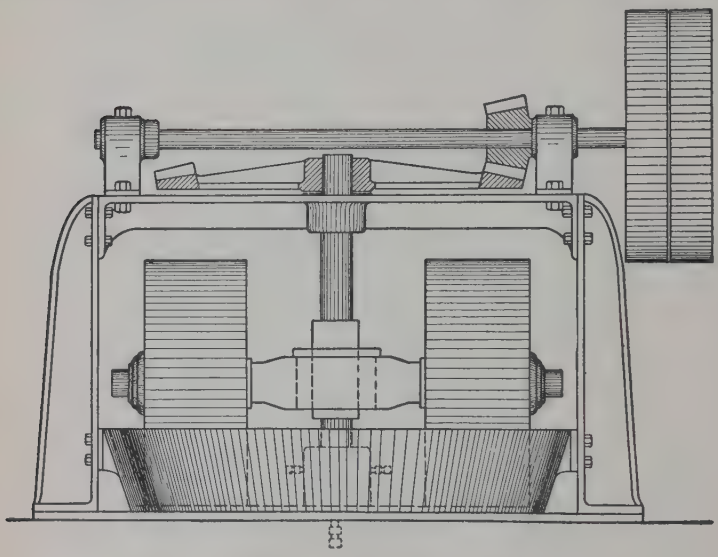


Fig. 136. Facing Grinder

very uniform mixture. The hopper may easily be removed to clean the plate. The machine is used for the final mixing.

Fig. 136 shows a foundry grinder or facing mill. It is the type of mill used for mixing loam. Either the pan or the rollers are attached to the driving shaft and made to revolve, crushing and mixing whatever is shoveled into the pan. Frequently, a stout blade, something like a plowshare, is fixed between the rollers, and prevents the mixture caking to the bottom of the pan. The faces of the rolls are of very hard or of chilled cast iron to withstand wear. When the loam mixture is sufficiently ground, it must be shoveled from the pan,

and delivered to the molders or stored temporarily. It will set if stored too long. This is the type of mill used in the steel foundries, for grinding the facing materials. The various sands are dumped into the pan at one side, and, when ground sufficiently, are shoveled directly from the pan into a centrifugal mixer. This prepares them for use.

Cleaning Castings. After a casting has solidified in the mold, the flash should be removed, leaving the casting in the sand. For light bench work and snap-flask work, the mold is lifted bodily and the sand dumped on the pile; the bottom boards are piled in one place, and the cases are piled in another ready for the next day's work. As the molds are dumped, the castings are removed from the sand and piled at the edge of the gangway. When all castings have been removed from the sand, the gates are broken and thrown in a pile by themselves. When cold enough to handle, the castings are removed to the cleaning room, and the gates and sprues are sent to the scrap pile. With heavier floor work, the clamps are removed as soon as the casting has set; the flash is rapped with a sledge hammer and is stripped off the mold, leaving the castings to cool gradually in the sand. Sometimes a sharp blow is given on top of the runner while it is still red; this breaks it off before the flask is shaken out. At a red heat, cast iron is very weak and can easily be broken.

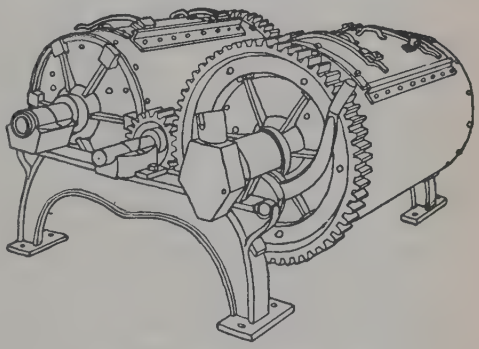


Fig. 137. Dustless Tumbling Barrel

Tumbling. The most effective way to clean small castings is in a rattling barrel. Fig. 137 shows a modern set of dustless barrels. The shell of the barrel is $\frac{5}{8}$-inch boiler plate riveted to cast-iron heads, with a door arranged to be entirely removed for packing and dumping. The bearings are hollow, and from one end the dust is drawn off through a galvanized-iron pipe. This pipe connects with an air-tight wooden chamber, as shown in Fig. 138, varying in size with the number of barrels connected with it. In this chamber hang a number of cloth-covered screens. An exhaust fan is connected to

this chamber at the opposite end from the inlet pipe. When the fan is in operation, a strong current of air is drawn through the barrels and through the chamber. The dust, entering the chamber, settles on the screens, so that but little dust escapes to the outside air. When necessary, the exhaust is stopped, and, by means of a crank on the outside of the dust chamber, the screens are shaken and the dust drops off, when it can be removed through a trap into an ash can or wheelbarrow.

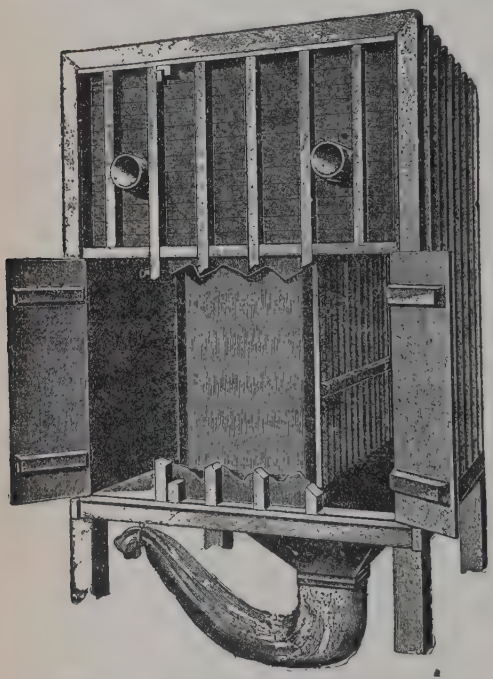


Fig. 138. Dust Collector for Tumbling Barrel

The driving shaft carrying the pinion revolves all the time, and any barrel may be thrown over into gear or drawn out of gear by the operation of a hand lever. The barrels should run about 25 revolutions per minute. Each barrel should be packed as full as possible with several shovelfuls of gates, shot iron, or hardened stars thrown in with the castings. The cleaning is accomplished in from 20 minutes to half an hour by the scouring action of castings, scrap, etc., rubbing against each other. Castings up to 50 or 100 pounds can be rattled, but only those of a similar character as to design or weight should be packed in together, otherwise the lighter castings will be broken by the heavier. When removed from the barrel, the work should show a smooth clean surface of an even gray color.

From the rattlers, castings go to the grinding room, where projecting gates or other slight roughness is removed on the emery wheel.

Heavy castings are cleaned by hand, by pickling, or by sandblasting.

Hand-Cleaning. When cleaning by hand, the worst of the sand is rapped off by light hammering, the remainder scraped off with old files and with steel-wire brushes such as that shown in Fig. 139. Some shops rub off finally with broken pieces of coarse emery wheel. Risers and fins are removed with cold chisels. The pneumatic chisel, shown in Fig. 140, is used as a timesaver. Where work is light enough to handle, small fins are removed by emery wheels; medium coarse wheels will cut faster on cast iron than fine ones, and will hold their shape better.

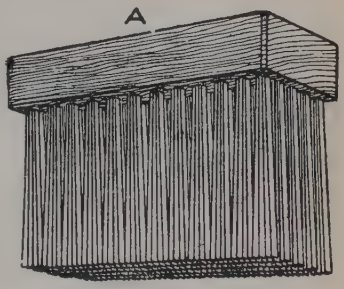


Fig. 139. Steel Bristle Brush

It is when castings must be cleaned by hand, that the value of a good facing dust shows itself. With the proper facing, the sand parts readily from the casting leaving a fine-looking smooth surface. With poor facings, on the other hand, the iron burns into the sand, making it hard to clean, and leaves a rough surface on the work.

Fig. 140. Pneumatic Chisel for Cutting Risers and Fins

Pickling. Pickling is a method of cleaning resorted to where there is much machining to be done on a casting. The work is placed in a pile on a suitable platform, and dilute sulphuric acid is thrown over it during one day, frequently enough to keep it well wet. The platform should be arranged to drain the acid back into the vat. Acid is diluted from 1:8 to 1:10. After about 12 hours' bath with acid, the castings are washed clean with hot water. The acid acts on the hard skin of oxide of iron which forms when the iron strikes the damp sand, and it eats through this skin to

the iron itself. The washing water should be hot enough to warm the castings sufficiently for them to dry rapidly without rusting. The acid must be thoroughly washed off, or it will continue to eat

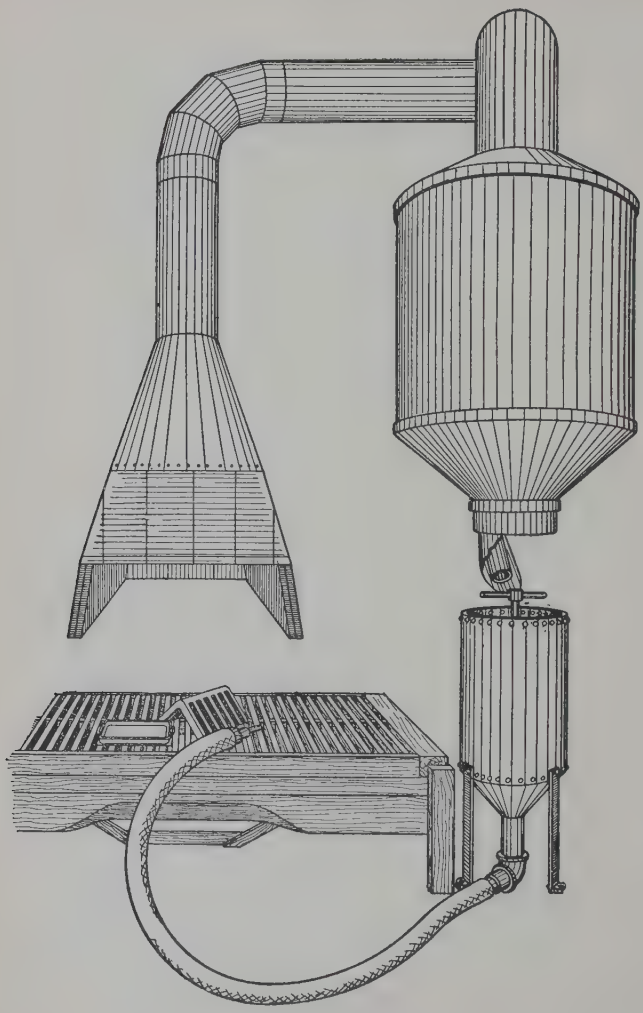


Fig. 141. Sand-Blast Arrangement

into the iron and cause a white powder—sulphate of iron—to form on the surface.

An excellent arrangement for a pickling department is to have the trough arranged on skids which allow it to be rocked endwise.

This drains into the pickling vat when acid is being thrown on, and into the gutter when the castings are being washed. Sheet lead is the best protective covering for small pickling troughs, but it is expensive and not durable enough to stand for heavy work.

Sand-Blasting. For castings of such shape and size that they cannot well be rattled, but are too small to be cleaned by hand, the sand blast has been used to advantage in many shops.

Fig. 141 gives an idea of the arrangement of the cleaning stall. Castings are placed on the wooden grating. By means of com-

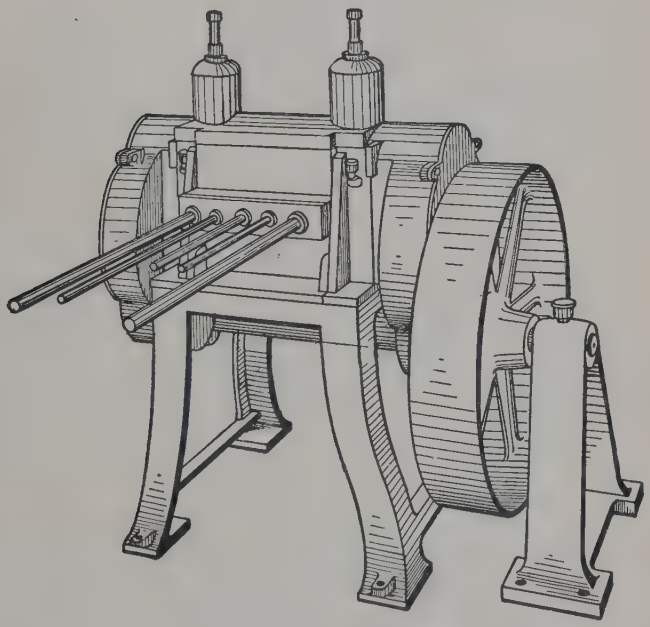


Fig. 142. Core Rod Straightener

pressed air a sharp silica sand is forced through a strong rubber hose and is directed against the castings by a hardened-steel nozzle. The operator wears a helmet supplied with fresh air by an air hose, to protect his eyes and lungs from the clouds of fine dust. An exhaust hood is arranged also to take off as much of the dust as possible.

The manual labor of this method is practically reduced to nothing, aside from handling the castings. The system, however, requires the installation of a rather considerable equipment, which has debarred its use in many foundries.

Re-Use of Core Rods. In removing cores, the bars become very much bent. In such shape they were formerly scrapped, or refitted to suit new cores with a hammer and block of iron. Fig. 142 shows a very practical power machine which delivers the bars perfectly straight. The machine consists of a pair of rolls, with different sizes of grooves turned in them, which pull a rod through a flaring mouthpiece and deliver it through a corresponding eye on the opposite side. The machines are made in different sizes, and take rods from $\frac{1}{4}$-inch to $\frac{3}{4}$-inch diameter.

STEEL WORK

Present Development. This class of work has developed within the last few years, and, beginning with the heavier parts of marine and engine construction, it is now crowding the field of drop forgings. Steel castings are malleable, and are very much stronger than iron ones. The principles of molding involved are similar to those in other classes of molding, but practice is varied to meet special conditions.

Processes. The art of making steel castings may be divided into three heads: (1) preparation and melting of the metal; (2) making and pouring the molds; (3) heat-treatment of finished castings. As the first and third heads come more properly under other departments, we shall here simply outline these processes, dealing in detail with the second heading only.

Characteristics of Metal. This branch of foundry work has developed to a great extent since the early nineties. The metal is similar in mixture, method of melting, and physical properties to the steel which is poured into ingot molds for forging purposes. The graphitic carbon is entirely burned out; the strength of the metal is therefore very much greater than that of cast iron. Combined carbon, manganese, and silicon are the elements depended upon for this strength; sulphur and phosphorus are kept very low. A typical analysis shows these elements in the following proportions:

Carbon	Manganese	Silicon	Sulphur	Phosphorus
0.27%	0.85%	0.35%	0.020%	0.025%

Owing to the purity of this form of iron, about 50 per cent more heat is required to melt it than is necessary in the case of pig iron—or about 3,300 degrees Fahrenheit. When melted, the metal runs

much more sluggishly than cast iron, and, on account of the absence of graphitic carbon, it does not expand at the moment of solidifying, and therefore does not take as sharp an impression. To insure as perfect an impression as possible, the molds are constructed with a good head of metal in the risers, and they are poured under pressure. The shrinkage is double that of iron; the risers are made very large, and are placed directly on the casting to insure feeding well. Great care must be exercised that neither mold faces nor cores bind during cooling, as such binding might cause a flaw.

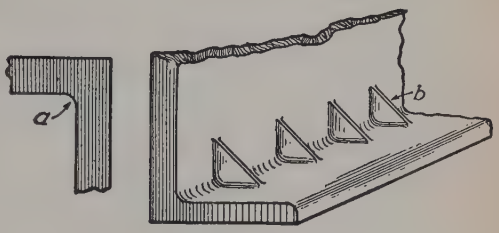


Fig. 143. Shrinkage Webs

Shrinkage. When two surfaces meet at right angles, the corner remains hot longest, and the sides shrink away, tending to cause a fracture at *a*, Fig. 143. To overcome this, thin webs are cut by the molder about every 4 inches or 6 inches—shown at *b*. These cool first, and hold the adjacent sides in position, preventing them from pulling away from each other. The internal strain due to this cooling is relieved by the annealing. After the casting is annealed, the webs are cut away.

STEEL MOLDS

Facing Mixtures. To withstand the high heat, pure silica sand is used as the basis of the facing mixtures for steel molds. Pure quartz or silica rock is quarried, and reduced to sand form through a series of rock crushers. At the foundry the necessary bond is given by the addition of fire clay and molasses water. These are thoroughly mixed with the sand in a facing mill and mixer, Figs. 135 and 136. A typical mixture is as follows:

1 barrow silica sand
3 pails powdered fire clay
Temper with molasses water

Where quartz sand is very expensive, the following mixtures, I, II, III, or IV, will reduce the cost. The old crucibles and fire brick should be crushed separately in the mill before mixing.

Ingredients	Proportions			
	(Castings up to 2 In. Thick)		(Castings over 2 In. Thick)	
	(I)	(II)	(III)	(IV)
Old facing sand	8	12	1	
Old crucibles	2		10	
Fire brick	2		5	
Fire clay	2	1	3	1
Coke	1		1	
Silica sand		5		5
Graphite		2		
Tempering medium, molasses water				

For *facing wash*, these mixtures are ground very fine, and thinned with molasses water.

Core sand for steel work is practically the same mixture as the mold facing. For thin metal a somewhat less refractory natural sand may be added to reduce the cost of the mixture.

For *small round or flat cores*, $\frac{1}{20}$ part rosin, with silica sand, tempered with molasses water, makes a good core. It should, however, be thoroughly burnt.

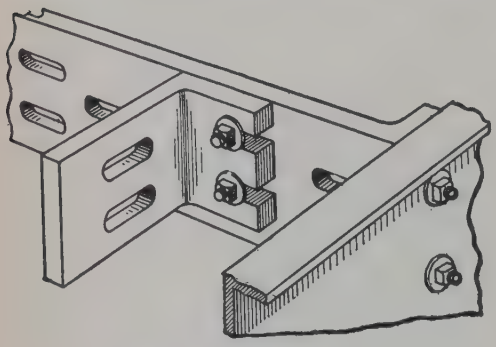


Fig. 144. Short Crossbar

For *core-wash* mixture, use 3 parts silica flour; 1 part Ceylon graphite; molasses water.

Flasks. Flasks for steel work are built of cast iron, Fig. 4, Part I. Full-length crossbars are bolted in the cope, 6 inches to 8 inches on centers, depending on the size of the flask. Short crossbars are fastened between these as needed, say 12 inches to 16 inches on centers, as seen in Fig. 144. Oblong bolt holes 4 inches on centers are cast in the sides of the flask and in all crossbars. Slots to correspond are cast in flanges of bars, so that they may be readily removed or shifted when fitting the cope to the pattern.

The holes for pins should be drilled to template in all flasks of the same size, so that copes and drags may be interchanged. Flask pins are slipped through the holes temporarily when the flask is being closed or opened.

On large work the cope is bolted to the drag while being rammed. The bottom plate is of cast iron, and is clamped to the flange of the drag with short clamps and steel wedges. The same tools are used for packing and finishing the mold as those described in connection with iron molding.

Flasks of from 18 inches to 48 inches in length have two handles bolted on the ends to lift them with. Larger flasks have trunnions, rockers, or U-shaped handles cast on the sides.

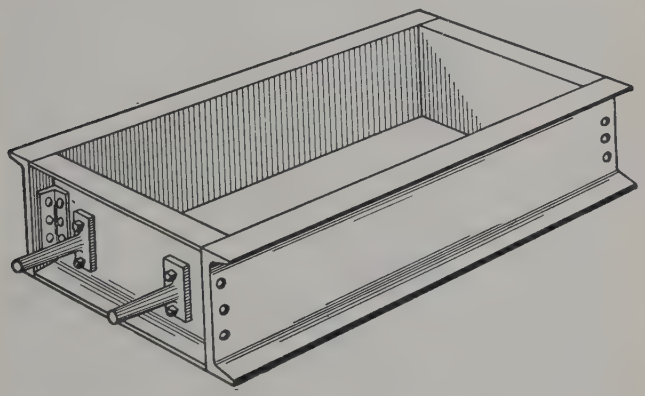


Fig. 145. Small Flask for Steel Molds

Fig. 145 shows type of convenient small flask built up of channel and angle iron, size 14 by 20 to 24 by 48 inches.

Packing. In packing the mold, place the pattern on the board and cover with $1\frac{1}{2}$ to 3 inches of facing, depending on the size of the job. Tuck well with the fingers. The facing is used as prepared by the mixer, not sifted. Set the drag on the board, shovel in heap sand, and ram the mold somewhat harder than for iron. Strike off, and seat the bottom plate, fastening it firmly to the flange of drag with clamps or bolts. When this is done, roll the mold over, and remove the moldboard.

Press with the fingers all over the joint surface, especially around the pattern, to make sure of firm packing. If soft places are

found, they should be tucked in with facing sand. When needed repairs are made, slick the joint all over. Use burnt core sand for making the parting.

Try on the cope and adjust bars to fit the pattern. Clay-wash the cope before packing. Put on necessary facing over the joint and the pattern. Set the gate on the joint, but place risers directly on the pattern. Set the necessary gaggers, shovel in heap sand, and

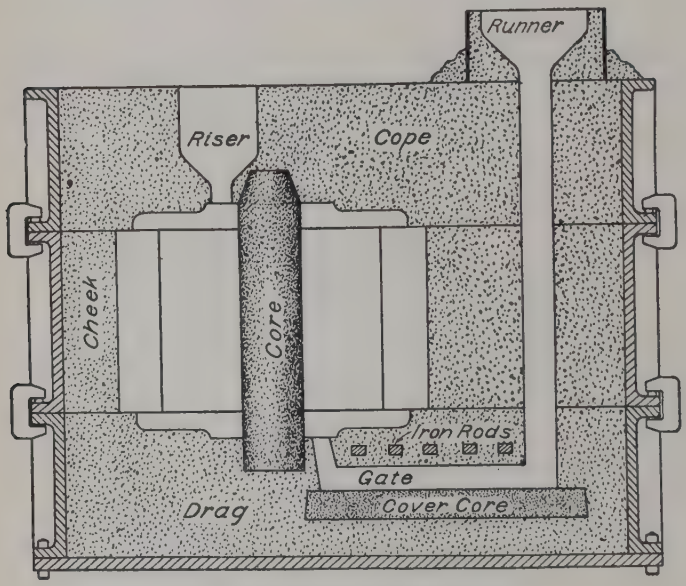


Fig. 146. Section Through Steel Mold

ram the cope. Vent well, lift the cope, moisten the edges, and draw the pattern.

In finishing the mold, nails are used freely, about $1\frac{1}{2}$ to 2 inches apart, driven in till the heads are flush with the surface of the sand. This is to prevent the cutting of the surface by the rush of hot metal when the mold is poured.

It is at this stage that the thin webs previously mentioned, are cut into the corner fillets where needed. The whole surface of the mold must be smoothly slicked over with the trowel and convenient slicks. When this is done, paint on the facing wash with a very flexible long-bristled brush.

Fig. 146 shows the section of a mold for a shrouded pinion, and illustrates the points above mentioned. The runner is lead in at the bottom by use of a cover core, as described in Dry-Sand Molding.

Molds for steel should be more than dried; they should be thoroughly baked to drive off every particle of moisture. This prevents the steel boiling in the mold and causing imperfections in the casting.

Where but little machine work is to be done on small work up to $1\frac{1}{4}$ inches thick, the molds may be made up in wooden flasks and poured green. For this class of work, only pure quartz sand and fire clay are used, tempered with molasses water. These may be made up and poured on the same day.

Cores. Cores for steel molds are made up in boxes similar to those used in the iron foundry. Although using special sands, the cores are strengthened with iron rods, vented with cinders, and provided with convenient hangers for lifting, as described in previous paragraphs.

Where cores must be made in halves, one set of half-cores may be made and baked. The other half is then made and rolled over directly on the baked half. Fire-clay wash is used to cement the joint. This method allows the joint between the halves of a core to be nicely slicked down.

Steel cores must be more collapsible than those for iron, on account of the excessive shrinkage of the metal. This is provided for in the mixture of the sand used, and by thoroughly baking the core to reduce the effect of the binding materials to a minimum.

STEEL CASTINGS

Running a Heat. *Open-Hearth Melting.* The melting of steel is a science by itself, and cannot be dealt with adequately in an article of this character. Only a very brief description of the process is given.

The main feature is the difference in application of heat. Metal is melted in what is termed the open-hearth furnace, a sectional plan of which is shown in Fig. 147. The charge of scrap steel and pig iron is placed on the central hearth. Heat is obtained by producer gas supplied with air blast. Both gas and air are heated in one set of regenerators before entering the combustion chamber. The flame

plays on top of the charge, and the waste gases pass off through the other regenerator section of the furnace, heating up its brickwork. The direction of the gases is changed about every 20 minutes. The regenerator is practically a tunnel about 15 feet long, filled with brickwork built up as shown in Fig. 148. About 4 heats a day are run from the furnaces.

Samples of the bath are analyzed at intervals during the heat. Guided by these analyses the proper proportions of ores, fluxes,

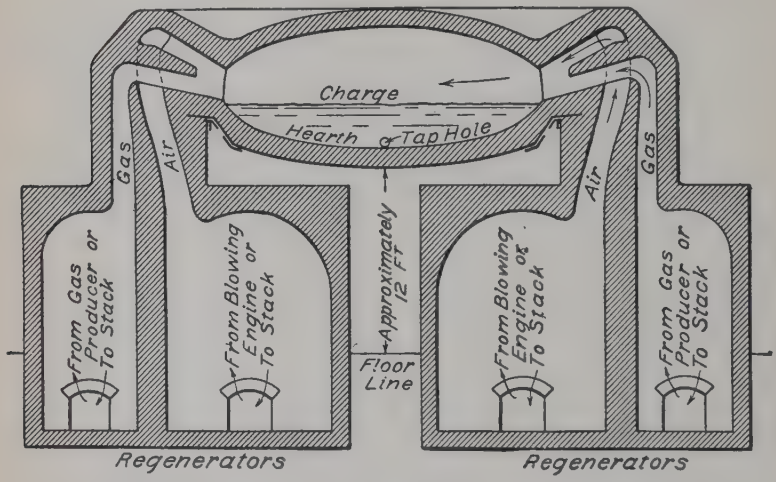


Fig. 147. Section through Open-Hearth Furnace with Regenerators

and pig are added to the bath to give it the right composition, a typical analysis of which has been given.

Pouring. When the bath is in proper condition, the entire charge, be it 5 tons or 40 tons, is drawn off into a ladle previously heated by a special gas burner. This ladle is lifted by the crane and carried to the pouring floor.

In order to secure the soundest metal free from pent gases or slag, all steel for casting purposes is tapped from the bottom of the ladle. The stopper is carried by a stiff round bar encased in fire-clay tubing. This passes through the liquid metal, as in Fig. 149, and may be raised or lowered by an arm attached to a rack-and-pinion mechanism bolted to the outer shell of the ladle and operated by means of a large hand wheel. The ladle is swung into position with the tap

hole directly over the pouring head. Four men hold the ladle steady with long iron rods. The metal thus enters the mold under the head of pressure of all the steel above it in the ladle.

When all the steel is drawn from the ladle, the latter is swung on its side near the furnaces, the stopper is removed, and all the slag possible is racked out. The ladles must be repaired after each heat, often to the extent of replacing one-half of the thin fire-brick lining. The casing of the stopper will last for but one heat, as the rod is sure to get bent out of shape. The rods are repaired by a blacksmith before recasing them.

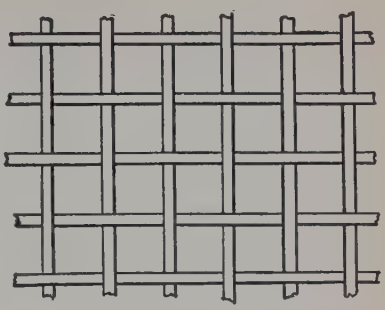


Fig. 148. How Brick Is Set in Regenerators

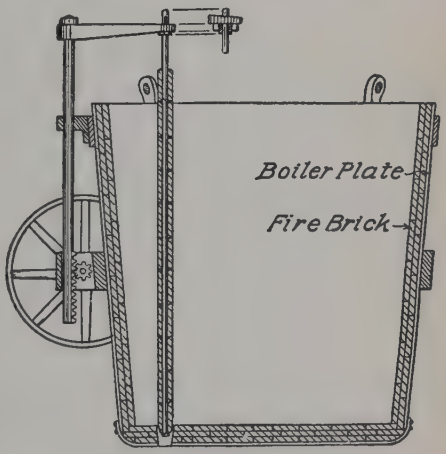


Fig. 149. Section of Steel Ladle

Setting Up Molds. Setting up is usually done by a different set of men from those employed to make the molds.

For convenience in pouring, runner boxes, such as shown in Fig. 150, and which serve simply as funnel-shaped mouths to the runners, are rammed up in small round sheet-metal boxes, using a wooden pattern to form the hole. These are baked in the oven.

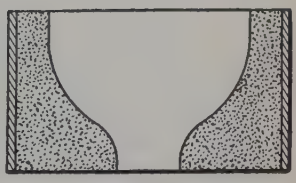


Fig. 150. Runner Box for Steel Mold

When the molds are properly dried, they should be removed from the oven, placed on the pouring floor, and have the dust blown out with compressed air. Now set the cores, close the molds, and clamp along joint flanges. Set runner boxes over the runners, and tuck heap sand around to prevent leakage. In pouring, a mold is filled only to the level of

the top of the risers. The metal drains from the runner box, thus allowing it to be used more than once.

Cleaning Castings. Steel castings do not run as smoothly as cast-iron ones, but they have this advantage, that, if they show only slight surface defects, the metal may be peened over with a hammer to improve appearance. The intense heat makes the metal burn into the sand greatly, so that cleaning is much more difficult, and the sand often must be almost cut from the castings by means of long cold chisels, struck with sledges. Pneumatic hammers are used to a large extent in cleaning and in removing fins and slight projections. Where shrinkage webs show, they must be cut out. Steel does not break off as does cast iron. The heavy gates and risers must be

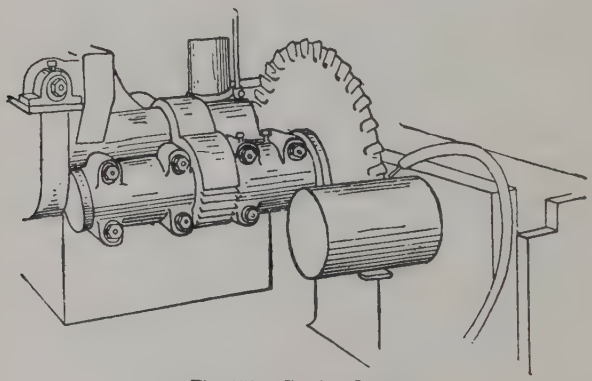


Fig. 151. Cutting Off Riser

removed by metal saws, as shown in Fig. 151, or by drilling a number of 1-inch holes side by side through the base of the riser and then breaking it off. The castings are generally annealed before the risers are cut off.

Annealing. In all steel castings of any size, cooling strains will develop on account of the shrinkage, and these should be relieved by annealing. In suitable trench-like ovens, the steel is heated to a dull redness. This allows the grain to assume normal conditions. The heating is usually done with a wood fire. Overheating renders the grain coarse, and weakens the casting. As indicated by the following figures, proper heat-treatment materially increases strength and toughness, and the work which is properly annealed is not only actually stronger, but being tougher, will stand more hard usage.

Conditions	Tensile Strength lb. per sq. in.)	Elongation (per cent)	Reduction of Area (per cent)
Raw	80,360	13.31	16.2
Annealed	81,767	27.6	40.4
Improperly annealed	79,421	14.3	17.8

MALLEABLE PRACTICE

Development. It is believed that early attempts to soften hard castings by reheating them, and the collection and publication of the results of these operations in 1722, by Réaumur, which led to the taking out of patents on the process by Lucas in 1804, comprised the early history of the malleable-iron industry

Seth Boyden of Newark, New Jersey, produced the first malleable iron in America. It is recorded that in 1828, The Franklin Institute of Philadelphia, Pennsylvania, awarded him a premium for the best specimens of annealed cast iron. These were mainly harness trimmings.

Before 1890, the secrets of the process of malleableizing were closely guarded, which accounts for its slow growth, but since then great advances have been made both in quality and tonnage, due to a better knowledge of the principles involved. As the industry now stands it is farthest advanced in the United States. It is estimated that for the year 1907 the output for all Europe was but 50,000 tons as compared with a production of 980,000 tons in America for the same year.

It is rather surprising that, while there is more skill required to produce malleables—and there are several extra operations—the price is so little in advance of that for gray iron. This is accounted for in part by the large number of castings ordered from a given pattern.

Comparative Characteristics of Metal. An idea of the value of this material is best obtained by a comparison of its properties with those of similar substances. Thus, gray-iron castings range from those nearly black in fracture, to white, with all degrees of softness up to glass hardness. They may be strong or weak and still serve their purpose. The desirable characteristics of the gray-iron casting is its extreme resistance to compression. Where great shock is to be cared for, great massiveness is required.

The steel casting has the highest strength of any cast metal: it may be deformed considerably without danger, and is cheaper than a corresponding forging.

The malleable casting is the connecting link between the two above mentioned. It is stronger than the gray casting but not as strong as cast steel. It can be bent or twisted considerably without breaking, and approaches gray iron in compressive strength; but its most valuable characteristic is resistance to shock. This property is best illustrated by the car coupler, a large number of drop tests having shown the value of the malleable coupler as compared with one of cast steel.

TESTING

Methods. There are two general ways for testing malleable cast iron: (1) by so-called shop tests; and (2) by laboratory tests of bars cast from every heat and annealed with the castings.

Shop Tests. The usual shop tests consist of bending occasional castings, as well as of twisting the longer pieces, and also of the making and breaking of test wedges. These wedges are about 6 inches long and 1 inch square for 3 inches of their total length, then tapering down in thickness to nothing for the last 3 inches, but keeping the full inch width; this gives thick iron as well as thin on the same piece. When the test wedges come from the annealing, they should be broken on an anvil by striking them with short light blows, the object being to see how much the thin end of the wedge can be bent before the piece breaks, after which, by holding the two parts together and observing the bend, a very fair idea of the quality of the castings these wedges represent, may be had.

Laboratory Tests. The regulation test bars are rectangular in form and are of two sizes: the 1-inch square bar to represent castings $\frac{1}{2}$ inch thick and over; while a 1- by $\frac{1}{2}$-inch section bar cares for the lighter castings.

The following specifications adopted by the American Society for Testing Materials form the only official standard in existence.

Specifications for Malleable Cast Iron

Process of Manufacture. Malleable-iron castings may be made by the open-hearth, air-furnace, or cupola process. Cupola iron, however, is not recommended for heavy or important castings.

Chemical Properties. Castings for which physical requirements are specified shall not contain over 0.06 per cent of sulphur or over 0.225 per cent of phosphorus.

Physical Properties. (1) *Standard Test Bar.* This bar shall be 1 inch square and 14 inches long, cast without chills and left perfectly free in the mold. Three bars shall be cast in one mold, heavy risers insuring sound bars.

Where the full heat goes into the castings, which are subject to specification, one mold shall be poured 2 minutes after tapping into the first ladle, and another mold shall be poured from the last iron of the heat.

Molds shall be suitably stamped to insure identification of the bars, the bars being annealed with the castings. Where only a partial heat is required for the work in hand, one mold shall be cast from the first ladle used and another after the required iron has been tapped.

(2) Of the three test bars from the two molds required for each heat, one shall be tested for tensile strength and elongation, the other for transverse strength and deflection. The other remaining bar is reserved for either tensile or transverse test, in case of failure of the other two bars to come up to requirements. The halves of the bars broken transversely may also be used for the tensile test.

(3) Failure to reach the required limit for the tensile test with elongation, as also for the transverse test with deflection, on the part of at least one test, rejects the castings from that heat.

(4) *Tensile Test.* The tensile strength of a standard test bar for casting under specification shall not be less than 40,000 pounds per square inch. The elongation measured in 2 inches shall not be less than $2\frac{1}{2}$ per cent.

(5) *Transverse Test.* The transverse strength of a standard test bar on supports 12 inches apart, pressure being applied at the center, shall not be less than 3,000 pounds with deflection at least $\frac{1}{2}$ inch.

Test Lugs. Castings of special design or special importance may be provided with suitable test lugs at the option of the inspector. At his request, at least one of these lugs shall be left on the casting for his inspection.

Annealing. (1) Malleable castings shall neither be over- nor under-annealed. They must have received their full heat in the oven at least 60 hours after reaching that temperature.

(2) The saggers shall not be dumped until the contents shall be at least black hot.

Finish. Castings shall be true to pattern, free from blemishes, scale, or shrinkage cracks. A variation of $\frac{1}{16}$ inch per foot shall be permissible. Founders shall not be held responsible for defects due to irregular cross-sections and unevenly distributed metal.

Inspection. The inspector representing the purchaser shall have all reasonable facilities given him by the founder to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made prior to shipment.

In general it may be said it is not necessary to have a metal very high in tensile strength but rather one which has high transverse strength and good deflection. This means a soft ductile metal which

adjusts itself to conditions more readily than a stiff strong product, for it is very hard to produce a strong and at the same time soft material, especially in the foundry making only the lighter grades of castings.

PRODUCTION PROCESSES

Preparing Molds

Patterns. One of the most important departments of the malleable works is the pattern shop. Malleable castings are comparatively light when considered in connection with general gray-iron practice and many times are ordered in enormous quantities from the same pattern.

Every refinement in pattern-making for light castings is found in this branch of the foundry industry. When developing a new article, the pattern-maker must practically live in the foundry. As trial castings are made he must measure them up with the pattern and make changes as found necessary; he must try them out again both before and after annealing, and with iron from different parts of the heat, and thus bring out new points calculated to help the molder and to lessen difficulties from shrinkage. It is the rule never to start an order for a quantity until the pattern has been tried out, the hard castings have been broken for evidence of shrinkage, and everyone has been satisfied it is safe to proceed.

Construction Difficulties. The terms shrinkage and contraction, as applied to malleable castings, should be clearly understood before any further mention is made of this subject. While *shrinkage* in gray-iron practice is often considered as the shortening of a casting in cooling, in malleable practice shrinkage means the tearing apart of the particles of iron in the interior of a larger section, close to a small one, leaving a spongy mass which is weak and very dangerous to the life of a casting. *Contraction* being simply reduction in size while the casting is cooling, amounts roughly to $\frac{1}{4}$ inch per foot in the hard, i.e., before annealing. During the annealing, about half of this is recovered, so that the net result is about the same as in gray-iron practice. It should be plain, however, that this big contraction causes the tearing as above mentioned when there are heavy sections which remain in a molten state a little longer than do adjoining light sections, unless liquid iron can be fed in. Where this is impos-

sible, the use of chills must be resorted to and fillets made much larger.

In gating patterns it is to be remembered that white iron chills easily and must be poured rapidly. To a certain extent, this limits the number of pieces that may be run successfully, unless the gates be made so large there would be danger of dirty castings. The runners should be large and the sprues heavy, the idea being to get a large amount of metal in front of the gate for the individual casting. The use of the match plate is largely resorted to also, as being well adapted to this class of work. Fig. 152 shows a group of three of the gated patterns in daily use in the Arcade Malleable Iron Foundry, Worcester, Massachusetts. In Fig. 153 there are shown 84 small thumb nuts on one gate; also 18 hinge patterns mounted on a match plate.

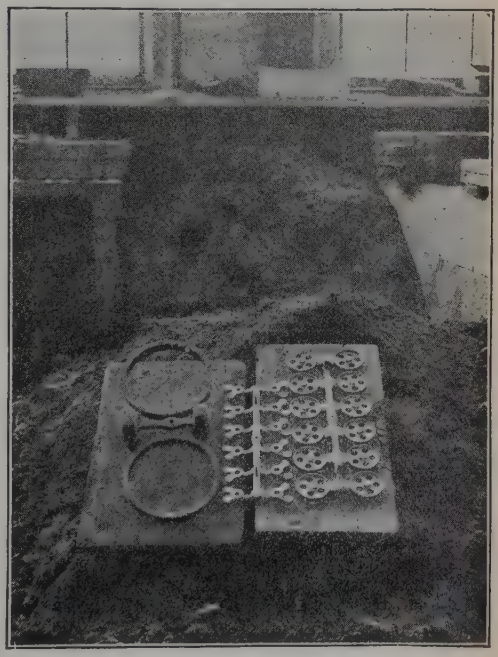


Fig. 152. Gated Patterns

Molding Methods. But little difference from ordinary gray-iron methods, occurs in molding practice other than in gating and in pouring. Since white iron melts at a somewhat lower temperature, there is less danger of sand burning into the casting, so less attention is paid to facing sand.

A large per cent of the work is made in the snap flask on the bench, as illustrated in Fig. 154. From the fact that nearly all work is in quantity, here is where molding machines may be used to great advantage. As these are explained elsewhere, no more need be said except that care should be exercised in the selection of types

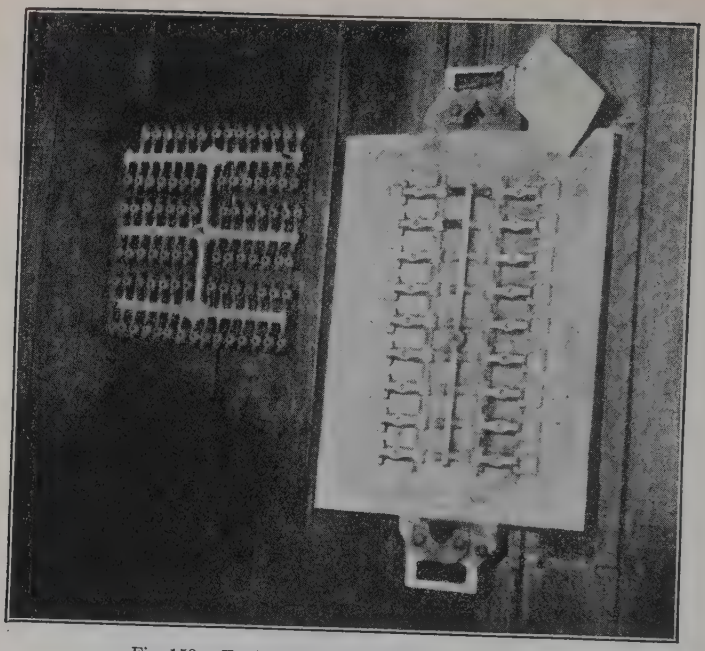


Fig. 153. Typical Gated Pattern and Match Plate

Fig. 154. Molds in Position for Pouring

Fig. 155. View of Molding Floor, Fig. 154, Taken from Opposite End of Plant

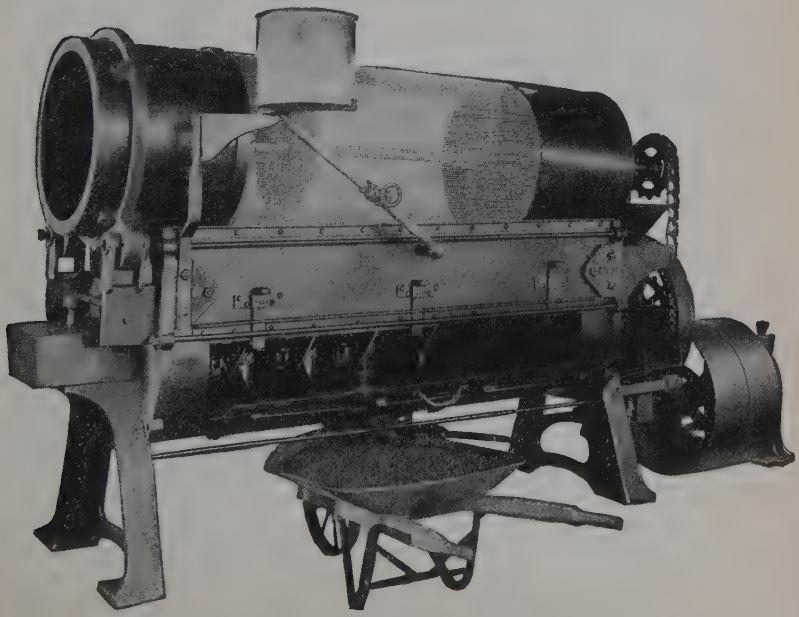


Fig. 156. Sand-Mixing Machine
Courtesy of Standard Sand and Machine Company, Cleveland, Ohio

best suited to local conditions. Fig. 155 is a view from the opposite end of the same foundry floor.

Flasks. While much of the work is handled in snap flasks, it is not unusual to find metal flasks closely conforming to the shape of the pattern, thereby greatly reducing the amount of sand to be handled, with a corresponding reduction in cost of production.

Cores. Practically all castings are cored and the problem is to produce a sufficient number of cores that there may be no delay for the molder. As there is no important difference in the preparation of cores—the same sand and binders being used—the large number required warrants the introduction of modern sand-handling and mixing machinery to a somewhat greater extent than in gray iron.

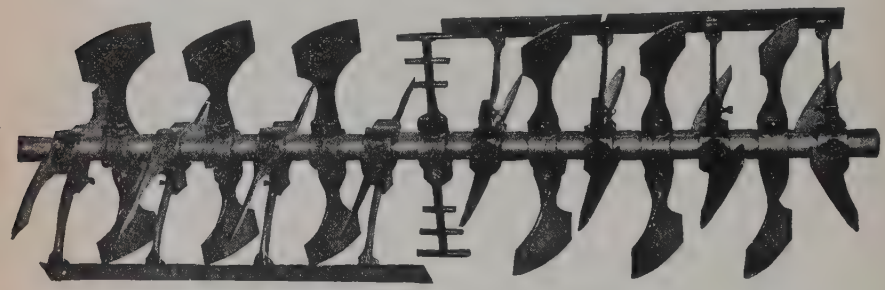


Fig. 157. Mixing Paddles of Standard Sand-Mixing Machine

The batch mixer alone proves of great value by the reduction of binder required due to its more even distribution; oftentimes this amounts to nearly 100 per cent. The type of batch mixer shown in Fig. 156 is made by the Standard Sand and Machine Company, Cleveland, Ohio. Fig. 157 is a view of the mixing paddles.

Melting Metal

Methods of Melting. Under this head the several methods in use will be described, which are as follows: (1) crucible; (2) cupola; (3) air-furnace; and (4) open-hearth.

Crucible Melting. The quality of metal produced by this method is without doubt of the best. Being melted out of contact of the fuel, there is no danger of absorbing impurities therefrom, but the small amount of metal available at one time limits the production to only the smaller work. Partly for this reason, the excessive cost of

production does not admit of competition with other methods which, while lacking somewhat in quality, yet meet actual requirements.

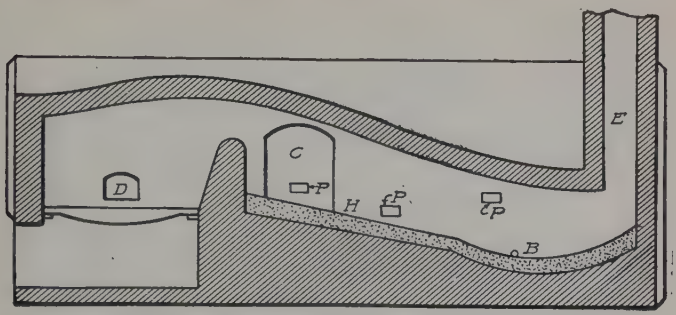


Fig. 158. Air Furnace with Bath at End Remote from the Bridge

A more detailed description of melting in the crucible is given in the subsequent section on Brass Melting.

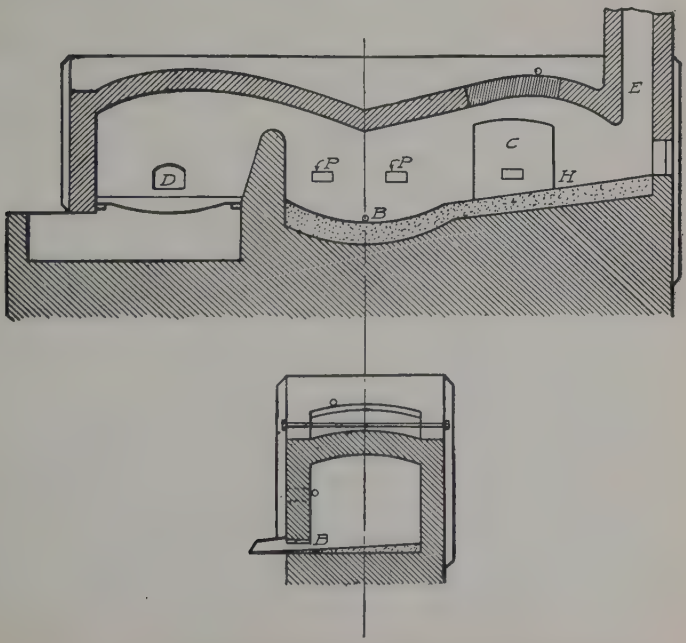


Fig. 159. Longitudinal Section of Air Furnace with Bath Immediately behind the Bridge

Cupola Melting. As in gray iron, the cupola offers the most economical method of melting iron, not only in cost of installation

and saving of fuel, but in ease of manipulation as well. It has some disadvantages which restrict its use, the greatest being the inferior quality of metal produced, which is caused by the contact of metal with the fuel, and also the danger of burned iron which in turn makes sluggish iron, with the result that castings are likely to show pinholes.

There is also greater difficulty in annealing—usually it requires 200 or 300 degrees Fahrenheit higher temperature. This method may be safely used only when the property of bending, rather than strength, is required. Pipe fittings form a large part of the production of the cupola method. However, it makes a convenient melting medium for the production of anealing boxes.

Fig. 160. Section of Roof of Air Furnace

Air-Furnace Melting. The number of furnaces of this type far exceeds all others. In the issue of the *Foundry Magazine* for February, 1910, the number of the different types of furnaces engaged in the production of malleable in America was given as follows: air furnaces, 369; cupolas, 42; open-hearth furnaces, 21.

Figs. 158 and 159 show two general types of air furnace. In the furnace represented in Fig. 159 the bath is immediately behind the bridge, while that shown in Fig. 158 has its bath at the end, remote from the bridge.

Fuel is placed on the gate through the charging door *D*, which is of cast iron lined with fire brick. The hearth *H* is where the metal is placed when charged. *E* is the stack through which the gases

finally escape. *B* is the bath where the molten metal collects and at its lowest point the tapping hole is located. The metal is charged by

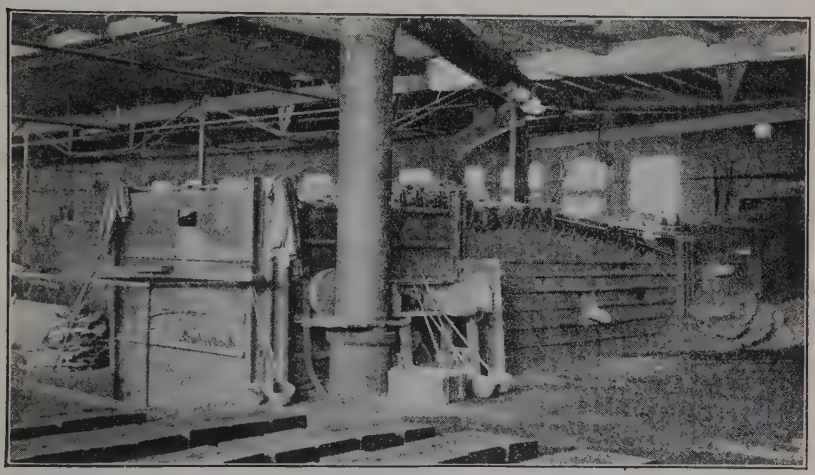


Fig. 161. Complete Installation of Air Furnace

removing a part of the roof as shown at *O*, a section of which is shown in Fig. 160. Peepholes are shown at *PPP*, which are for observation.

Fig. 162. View Showing Method of Firing Air Furnace

The iron is charged on the hearth so as to leave openings between the pieces, and the molten metal should be skimmed from time to

time so that it may receive the direct action of the burning gases passing over it.

Fig. 161 shows a type of air furnace complete. Fig. 162 is a view of the opposite side with a melter in the act of firing. Fig. 163 shows the slag hole, and the slag just skimmed off.

The air furnace requires greater skill to operate than does the cupola, and the fuel ratio is higher, but, if of good quality and

Fig. 163. Slag Hole

properly fired, is not excessive and should average about 3 of metal to 1 of fuel.

Open-Hearth Melting. It is said the open-hearth installation represents the highest type of melting yet devised, but the high first cost, combined with frequent and heavy repairs and skill required to operate, confine its use to the largest plants, and as long as the trade is satisfied with the quality of the product of the more easily operated air furnace, it is quite doubtful if the open hearth will be generally adopted. The description of the open-hearth furnace which has been given in Steel-Casting Practice may be referred to.

Iron Mixture. Without the proper mixture of iron no furnace will produce satisfactory iron, hence the importance of using the greatest care in this part of malleable practice.

That the reader may clearly understand the basic principles involved, it is necessary first to discuss the various materials entering into the mixture. These include pig iron, sprues, faulty castings, annealed scrap, steel scrap, and ferro-alloys.

Good Composition. As all the materials have a bearing on the finished casting and should only be used as they affect this, it is at this time well to give an analysis for good malleable castings, which is as follows:

Element	Proportion (per cent)
Silicon	0.75 to 1.25
Carbon	3.00
Sulphur	0.04 (extreme)
Manganese	0.60 (extreme)
Phosphorus	0.20 (extreme)

There is considerable latitude allowed due to the class of work to be produced. Makers of heavy castings exclusively may specify their silicon from 0.75 to 1.50 per cent, while for very light work silicon from 1.25 to 2.00 per cent may be the rule. Total carbon should never run below 2.75 per cent in the hard, i.e., before the annealing. Manganese should average about 0.40, not much lower, and never above 0.60. Sulphur should always be as low as possible, 0.07 per cent being the high limit in the casting, hence the necessity for choosing irons for the mixture which will insure this. Phosphorus below 0.225 per cent is desired.

Pig Iron. Formerly it was thought that only charcoal pig was suitable for malleable practice, but today, owing to improved blast-furnace practice, coke irons which are known to the trade as *coke malleable* give first-rate results and are used to a considerable extent, yet it is seldom that the writer has heard of a mixture that did not include one or more of the well-known brands of charcoal iron known to the trade as *Mabel, Briar Hill, Hinckley,* and *Ella.* It is generally conceded that a mixture containing several brands of iron, or at least two or three grades of the same brand, produces better castings.

Scrap. The next problem which presents itself is the disposition of gates, sprues, and discards, which are daily accumulated in the works, and the per cent of which varies with the class of work

produced, running as high as 60 per cent in the lightest work or not exceeding 25 per cent for very heavy castings. From this it will be seen that it is quite likely to be a varying element. The practice of taking the silicon content for every heat before castings go into the annealing operation gives opportunity for fairly exact calculations. Corrections may be made in the mixtures as may be found necessary, otherwise, should there be an accumulation of such material, it would soon become an unknown quantity and so be a source of annoyance as well as of loss to the management.

The annealed scrap offers more difficulties owing to the effect which even small amounts have on the quality of the product. Quite frequently there is no attempt to use this in the regular mixture but rather to utilize it in the production of annealing pots of which more will be said later.

The use of steel scrap in malleable mixtures is proving beneficial although the amount is at present limited to something like 10 per cent. This material should not be charged with the regular mixture, but should be introduced into the bath of molten metal so that it may be quickly covered by the protecting slag, for the steel must not be allowed to burn as this would seriously injure the quality of the castings.

It is also possible to use small amounts of gray-iron scrap, though it is seldom necessary to do so, and usually 5 per cent is the limit.

Ferrosilicon. This material is carried in stock, either as a 0.50 or 0.75 per cent alloy for use in the ladle, or as a 14 to 20 per cent pig for use in the furnace.

In choosing metals for the heat it first is necessary to ascertain the silicon content desired in the castings, and then to select such amounts of the different brands of pig iron at hand as are required to bring about the desired result, first making careful calculation of the amount of scrap to be cared for and its effect on the mixture as regards its silicon content. The previous section on Melting may be referred to regarding gray-iron mixture.

In conclusion, it would be well for the reader to clearly understand that it requires greater skill to produce malleables, and for this reason a well-equipped laboratory and a good metallurgist are almost necessities where high quality is the order of the day.

Malleable Casting

Variation from Gray-Iron Practice. The furnace having been duly charged for the day's melt with the desired mixture of metal, we will now consider the casting operation which differs only from gray-iron practice in that the metal contains a larger per cent of carbon in the combined form, melts at a lower temperature, and also cools more quickly in the ladle, and for this reason must be handled more rapidly. The hand ladles are of somewhat smaller capacity, usually about 25 pounds, as compared with 40 to 60 pounds in gray-iron practice.

Carrying. This lighter burden allows the molder greater freedom in his movements. It is common practice to see the molder catching-in to the stream of molten metal and running to his floor that the molds may receive the benefit of the hottest metal possible. While this is possible in malleable-iron work, with the larger ladles of gray-iron practice, this would not only be exhausting, but highly dangerous as well.

It must be remembered that the majority of work is light and that the floor space required for the setting-up of sufficient molds to pour, say, a 30-ton heat, is considerable, and even with the furnace located as it should be in the center of the works, there must be long carries. These are in part overcome by the installation of some overhead trolley system using 500-pound ladles; and where the nature of the work permits—i.e., it is not too light—this method is of course preferable.

Cooling. As there is great danger of the castings developing cracks if exposed to the air while still red hot, it is far better practice to let them remain in the sand until they are at least black hot when they may be safely shaken out: the exception being some special work, as brake wheels, for example, in which there are developed great casting strains. In this case it is found best to shake out while still red hot and quickly place them in a so-called reheating oven which is already fired very hot. This furnace, after being fully charged with the day's output of this special work, is closed and the fire allowed to die out over night, when the castings will be found to be partly annealed, though not in a malleable sense. This treatment is found of considerable value in certain classes of work which otherwise might be hard to save.

Cleaning Castings. The castings having become cool so that they may be readily handled, a rough separation of castings and gates should be undertaken and the cores removed as far as possible, after which the castings should be inspected and all missruns or otherwise defective castings removed. The discards along with the gates and sprues should then be tumbled to remove the sand scale before being returned for remelting, otherwise it would form an excessive slag and require a larger amount of fuel to remelt.

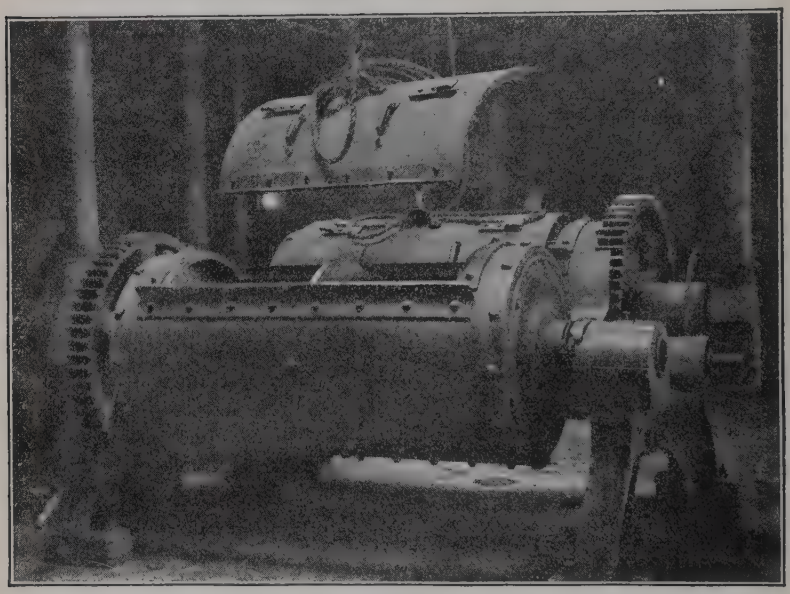


Fig. 164. Modern Exhaust Tumbling Barrel

Hard-Rolling. After this rough sorting the castings are ready for the hard-rolling room which contains a series of tumbling barrels, all of which should be equipped with an exhaust system, or else the dust created in this department will become the bane of the plant. Fig. 164 shows an installation of modern exhaust tumbling barrels.

The castings should be rolled only long enough for the removal of the sand scale, usually accomplished in from 20 to 30 minutes. Some classes of work may be so delicate that it would be impossible to clean them in this manner without too great a loss from breakage, and in such cases the acid bath may be resorted to, or perhaps the

sand blast which is fast superseding other methods of cleaning all classes of castings. Fig. 165 shows a New Haven sand-blast tumbling barrel which is well adapted to this work.

After this hard-rolling process the castings are removed to the trimming room where the gates and fins remaining may be easily removed with a hammer, thus saving much time in the grinding room after the annealing.

Annealing. We now arrive at one of the most important departments of the plant. No matter how carefully all previous operations may have been conducted, all will have been in vain should any

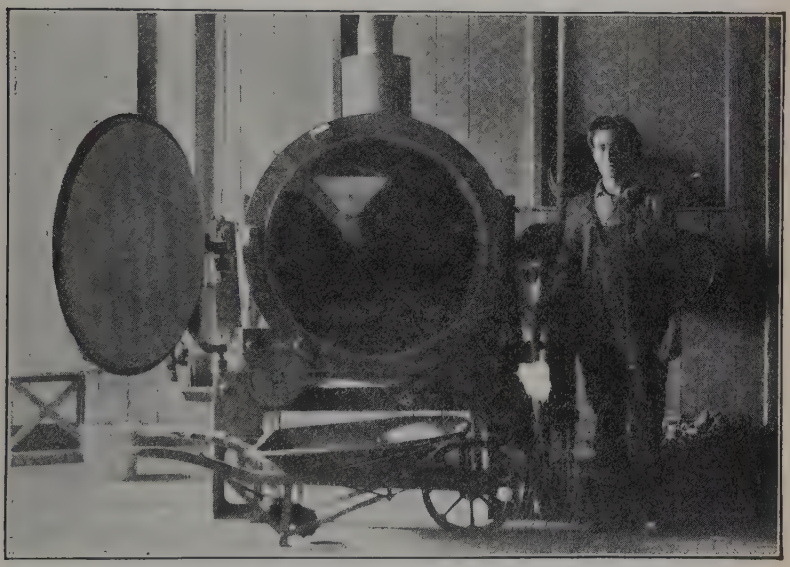


Fig. 165. Sand-Blast Tumbling Barrel

neglect creep into this part of the practice, for it is here that the very nature of the casting is changed from its hard and brittle state showing a white fracture, to the so-called black-heart malleable, the fracture showing a steely rim with a black velvety core.

This change is brought about by gradually bringing the temperature in the annealing ovens up to about 1600 degrees Fahrenheit, and by maintaining that temperature from 3 to 4 days, after which the fire is allowed to slowly die down; this whole process requires from 8 to 10 days. There have been attempts made to shorten this

annealing process, usually by increasing the temperature some 200 degrees, thereby reducing the total period of the process to about 6

Fig. 166. Packing Annealing Boxes

Fig. 167. Hand Charging Truck

days; but this has been done at the expense of quality, and the best results are obtained by the former method.

Preparation of Castings. After inspection in the trimming room, the castings are brought to the annealing room which has its floor

space divided into two parts—the packing floor, and the ovens. There are usually two rows of ovens, one on each side of the building, and the clear space between is used for packing the pots and also for dumping them after the annealing. The floor of this is made of 1-inch iron plates.

The annealing boxes, or laggers, may be either square or round, or perhaps more generally oblong, and are first cast 1 inch thick. These pots are piled three or four high—the first one is placed on an iron stool—all joints being luted up with mud made by adding water to the burnt sand from the rolling room with perhaps the

Fig. 168. Interior View of Annealing Oven

addition of a little fire clay. The scale used for packing is cinder squeezed from muck balls where wrought iron is made. It was formerly the practice to spread this scale upon the floor and sprinkle it daily with a solution of sal ammoniac to rust it, but later-day practice has proven this unnecessary.

As the castings come into the annealing room the operator places a pot on the stool, shovels in some scale, carefully placing in a layer of castings in such manner that none comes in contact with the sides of the pot or no two castings touch each other, then more scale and more castings are added until the pot is filled, as shown in Fig. 166. On this another pot is placed and duly packed, this to

be continued until the pots are piled as high as desired, after which all joints are sealed with mud making the whole pile more or less

Fig. 169. Oven Charged

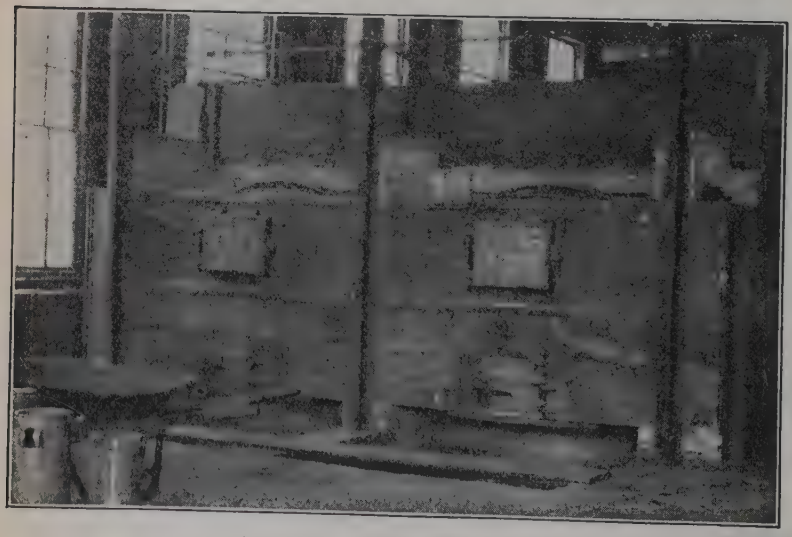


Fig. 170. Ash Pit and Firing Doors

air-tight. After this has been accomplished, the pots are placed in the oven either by a hand or by a power charging machine, as illustrated in Fig. 167.

Oven. The annealing oven is quite simple. The principle involved is the introduction of heat from some convenient point and its distribution in a uniform manner, and the introduction of as

Fig. 171. Final Sorting of Castings

Fig. 172. Shipping Room

little air as possible. The combustion space should be no larger than necessary, the draft regulation perfect, and the bottom of the oven underlaid by a series of flues which allow the gases to circulate

before escaping into the stack, so there may be as little loss of heat as possible. Oil, gas, or coal may be used for fuel as best adapted to the locality.

Fig. 168 shows the interior of an oven, while Fig. 169 shows the boxes in place. Fig. 170 is a side view of an oven showing the firing doors and the ash pits. Having placed the full number of

Fig. 173. Recording Pyrometer
Courtesy of The Bristol Company, Waterbury, Connecticut

boxes in the oven, the front is closed and the ovens are fired. As before stated this operation requires from 6 to 10 days from the time the fire is started until the oven has cooled sufficiently to allow the removal of the boxes.

As the boxes are withdrawn from the oven and are taken to the floor of the annealing room, they are suspended from an overhead trolley, or by a crane, and the castings are removed by striking the

boxes several sharp blows with a medium-weight sledge hammer, the castings and scale falling upon the floor. The castings are now picked from the scale and it will be noted that there is some tendency for the scale to adhere to them. This may be removed by the ordinary rolling barrels, after which any gates or fins remaining should be ground off. The amount of labor required for this operation depends upon how carefully the gates were moved while castings were in the hard. After a final inspection, the castings should be ready for shipment. Figs. 171 and 172 show the castings being sorted out and ready for shipment in the shipping room.

Pyrometer. The use of the pyrometer in connection with the annealing furnace is almost obligatory. Fig. 173 shows a standard type of recording pyrometer. The pyrometer equipment is often placed in the office of the head executive of a local plant; it is possible for him to plug into any two of his battery of annealing furnaces at any time during the day. Also, in the morning, there is recorded a true record of temperatures for the night before. As no operator knows whether his furnace is under observation or not, this system has the tendency to keep the men at all times alert.

Finishing. The amount of finish given the castings varies with local conditions and class of castings produced. There are some classes of work where, by the use of leather scraps in the soft-rolling room, the work is so carefully cleaned and polished that the castings may be tinned or nickeled and sometimes gold- or silver-plated, making very beautiful work in which great strength is combined with cheapness of production.

BRASS WORK

ALLOYS

Distinctions. Cast iron, cast steel, and malleable iron, which we have previously considered, are three forms of the same metal—iron. The difference in their physical characteristics is due solely to a variation in the proportions of certain elements or metaloids combined with the iron.

The metals to be dealt with in this section are termed *alloys*—that is, mixtures of two or more separate metals. The common alloys in use in the foundry, for casting various machine parts, are

made from combinations of copper, tin, and zinc, and are called *brass*, or *bronze*.

Brass and Bronze. Although the term brass is held by some authorities to cover any of these combinations, the general classification accepts brass as an alloy of copper and zinc, and bronze as an alloy of copper and tin. In some sections the latter is spoken of as *composition*.

Bronze has been used by man in all ages. Centuries before the Christian Era the Egyptians employed it for making coin, armor, and weapons, as well as household utensils, and statuettes of their gods. Analyses of many of these ancient relics show the composition to be almost identical with the bronzes of the present day. Brass also was in use before the time of Christ, but unquestionably bronze was of earlier origin.

Metals. A short discussion of the separate metals will help in understanding the properties of their alloys.

Copper. Copper has a red color; it is hard, ductile, and very tough. It melts at about 2000 degrees F.; but it is difficult to make castings of the pure metal. Copper does not rust as does iron, and is one of the best conductors of heat and electricity. For this reason it is largely used in sheet form as a sheathing metal, and in the form of wire or rods for electrical transmission. Casting copper is put on the market in ingots of special form weighing from 18 to 25 pounds each.

Tin. Tin is a white lustrous metal, very malleable, but lacking tenacity. It may be reduced extremely thin by rolling, as is shown by tin foil. It melts at 450 degrees F. When a bar of tin is bent it will give a crackling sound known as the cry, which at once distinguishes it from other metals such as solder, lead, etc., which have similar external appearance. It is put on the market in pigs weighing about 30 pounds and also in bars of about 1 pound each. Its cost is approximately $1\frac{1}{2}$ times that of copper and 5 times as much as zinc. Tin may be cast unalloyed, and is sometimes used to run pattern letters or small duplicate patterns cast in zinc chill molds. The addition of $\frac{1}{3}$ to $\frac{1}{2}$ by weight of lead gives a cheaper metal, however, and one that will run equally well.

Tin mixed with copper gives greater fluidity, lower melting point, and greater strength, changing the color from red to bright

yellow. Serviceable alloys may contain as high as 20 per cent of tin. This gives a metal of golden yellow color, very hard, tough, and difficult to work. With larger percentages of tin the color shades to gray, the metal is hard, brittle, and has little strength, and has no value for engineering purposes.

Zinc. Zinc has a bluish white color; it is hard, but weak and brittle. The fracture shows very large crystals of characteristic shape. It melts at about 700 degrees F., and shrinks but little in cooling. For this reason it may be used to cast directly for small metal patterns to form chills from which soft-metal castings may be made for duplicating these patterns. If exposed to the air at high temperatures, zinc will volatilize, that is, turn to a gas and burn. It burns with a bluish flame, and throws off clouds of dense white smoke. For this reason great care must be used to keep the air away from it as much as possible when being melted or mixed in an alloy, for, aside from the loss of metal, an oxide is formed in the mixture which impairs the quality of the alloy.

Zinc is known in commerce under two names: when rolled into sheets it is called *zinc;* when in ingot form for casting, it is called *spelter.* These ingots are flat, approximately 8 by 1 by 17 inches, and weigh about 30 pounds. In this form they may be easily broken in small pieces for convenience in charging.

Zinc may be added to copper in a very wide range of proportions, the alloy increasing in hardness and losing ductility with the increase in the proportion of zinc. The color changes from the red of the copper to a full yellow when $\frac{1}{3}$ zinc is used. Further additions of zinc change the color to red, yellow, violet, and gray. The alloys are serviceable up to 40 or 50 per cent of zinc.

When zinc is mixed with melted metal, considerable reaction or boiling takes place, which tends to make a more thorough mixture and to drive impurities to the surface. For this reason a small proportion of zinc—2 or 3 per cent—is often stirred into bronze mixtures after the pot is drawn.

Lead. Lead has a bluish white color, and considerable luster when freshly cut. It is malleable, soft, and tough, but very weak. It melts at about 600 degrees F.

Lead is not used by itself as an alloy with copper. A very small proportion may be added to the standard mixture for brass or bronze.

TABLE VI

Proportions of Mixtures

Use	Copper		Tin		Zinc		Lead	
	(per cent)	(ounce)	(per cent)	(ounce)	(per cent)	(ounce)	(per cent)	(ounce)
Gun metal—for bearings; very tough hard mixture	83	16	12	2½	2.5	½	2.5	½
Steam or valve metal—cuts freely; very tough; resists corrosion	85	16	7	1¼	5	¾	3	½
Composition metal—for general use on small machine parts	90	16	5	1	5	½		
Art bronze—rich color; runs fluid at comparatively low heat	90	16	6	1	3	½	1	¼
Common yellow brass—for general run of machine castings	66.5	16			33.5	8		
Brass—to machine easier than the above; for same purposes	66	16	33			8	1	½
Antifriction metal—for journal boxes	1.8	1	64.7	32	33.35	16	1	½
Mixture—for small patterns; runs well; shrinks little			66	2			34	1

It will cause them to run more fluidly in pouring, and be softer for machining. For this reason, lead is added to bearing mixtures to advantage. But it tends to deaden the color and reduce the conductivity of the metal for electrical purposes.

Mixtures. *General Proportions.* The percentages given in Table VI are for convenience in comparison and for figuring large heats. The beginner, however, will generally melt but 1 or 2 pigs of copper at one time. These he will weigh first, and then figure the other portions of his mixture from this weight. In this case a formula given in pounds and ounces is much simpler.

Variation. From what has been said, it is understood that it is possible to vary these mixtures to meet special conditions. To harden or toughen an alloy, increase the tin; to soften it, reduce the tin. The same is true with zinc, but it will require larger proportionate changes in this metal to effect similar results in the alloy.

Phosphorus. Phosphorus is not a metal, but is a very active chemical element manufactured from bone ash. It has such an

TABLE VII

Phosphor-Bronze Mixtures

Element	Proportions of Alloy			
	Hard		Tough	
	(per cent)	(pounds)	(per cent)	(pounds)
Copper	87.5	$8\frac{3}{4}$	90.	9
Tin	12.25	$1\frac{1}{4}$	9.75	$\frac{1}{2}$
Phosphorus			.25	$\frac{1}{2}$
Phosphor tin	0.25	$\frac{1}{2}$		
Total	100.	10	100.	10

affinity for the oxygen of the air, that in its pure state it must be kept under water, because the slightest scratch would cause it to burn fiercely. It forms the principal substance used in making the heads of matches.

As a rule it is never used in the foundry in its pure state. For the production of phosphor-bronze castings there are several combined forms of phosphorus on the market. The most convenient of these is known as *phosphor tin*, which is metallic tin carrying various fixed percentages of phosphorus, of which 5 per cent is one very common proportion. Knowing the amount of phosphorus carried by the tin, the exact proportion for the entire alloy may be readily calculated. This element should not be used in alloys containing zinc or lead.

Phosphorus acts as a flux, combining with any oxidized or burned impurities in the bath of metal and driving them to the top. It tends to make the tin crystalline in form, in which condition it unites more firmly with the copper. It apparently unites chemically with copper, making that metal harder. The proportion of phosphorus should not exceed 0.75 per cent, while 0.25 to 0.40 per cent are safer proportions.

Two typical mixtures, one using 5 per cent phosphor tin, are given in Table VII.

PRODUCTION

Molding Materials. Natural molding sands are used for brass work. They are usually finer than sands used in iron work, because

brass parts are generally small and often have fine detail which must be brought out very sharply in the mold. For this reason, also, the sands should have more alumina or bond than iron sands. This increase of bond is possible because the metals entering the mold are not as hot as iron would be, and therefore do not require as much vent, but they have a greater tendency to cut the mold.

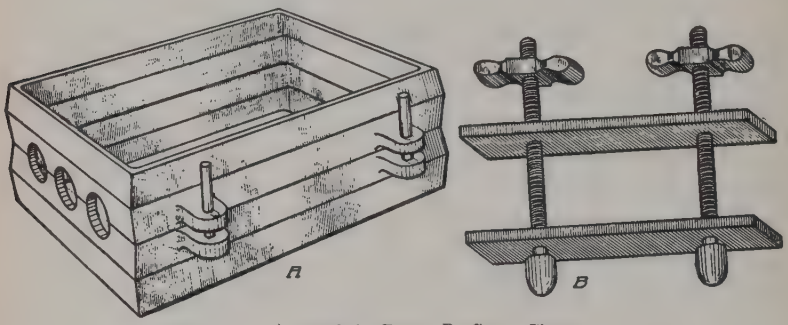


Fig. 174. *A*—Flask for Brass; *B*—Screw Clamp

For the general run of work the whole heap is kept in good condition by the frequent addition of new sand, but on large work a facing mixture is used similar to that of the iron foundry.

Burnt sand, powdered charcoal, and partainol are all good parting materials; the last two are best on small work, as they make a cleaner joint. Since they make a good facing for the mold, they are not blown off of the patterns.

Fig. 175. Spill Trough

Equipment. *Tools.* The brass molder uses practically the same kind of tools, such as shovels, sieves, rammers, and molder's tools generally, as already have been described.

Flasks. Snap flasks may be used, but the pins, hinges, and catches must be kept in careful adjustment so that the parts of the mold shall register perfectly. The same is true of the larger box flasks for floor work.

The most typical brass flasks are of cast iron with accurately fitting round steel pins, as seen in Fig. 174 at *A*. They have holes on the joint at one end of the flask so that the mold may be set upright when pouring. This gives a decided additional pouring pressure with a minimum thickness of sand over the castings.

Boards without cleats support the sand in the flask, and the whole is clamped, before setting on end, by means of some form of double-screw clamp similar to the illustration *B*, in Fig. 174.

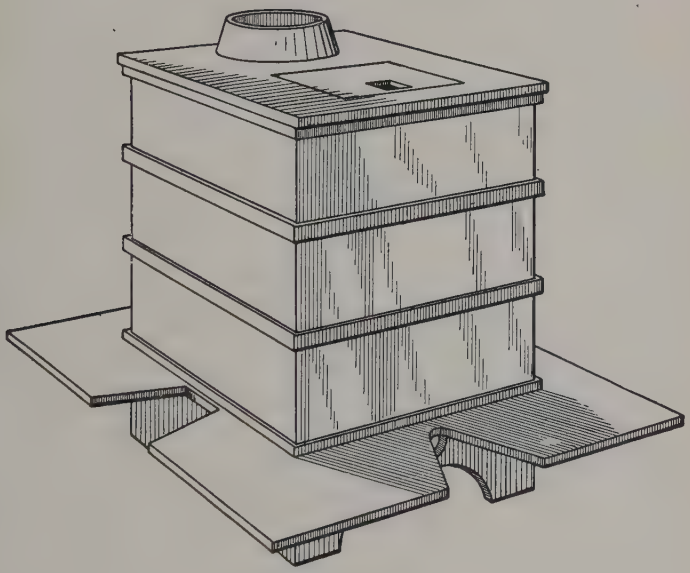


Fig. 176. Drying Stove

Spill Trough. Great care is taken in the brass shop to save all the shot and spilled metal possible. To this end, when the molds are to be poured on end, they are leaned against a cast-iron spill trough such as shown in Fig. 175. There should be a 1-inch layer of sand over the bottom of this tray. The crucible is held over it when pouring the molds, thus making it possible to conveniently catch, any metal that is spilled.

Drying Stove. For thin work the face of the molds are skin-dried to drive off the moisture before the metal enters the mold. Drying stoves, similar to that shown in Fig. 176, are used for this purpose. When the mold is finished, the two halves are carefully

sprayed with a weak molasses water, and the flask is set on end on the wide platform with the face of the mold next to the stove. When sufficiently dry, the mold is closed and poured at once.

Principles of Work. *Size of Heat.* Brass work deals, as a rule, with smaller quantities in every way than does iron work. The patterns are generally smaller, and the brass molder takes particular pride in making all his joints so neat that hardly a fin shows on his castings. The matter of catching the shot metal has been mentioned. Up to the time of the introduction of the oil-melting furnace, it was customary to heat a pot of metal for each molder. These heats were comparatively small, so that the molder would make up possibly 6 or 8 molds, then draw his pot and pour them, running in this way several heats in a day. Using the furnace, several heats are run each day, but a much larger quantity of metal is melted at each heat, so that the work of several molders is poured with exactly the same metal.

Molds. A mold for brass should be rammed about the same as for iron. On name plates and thin work, after the initial facing of sifted sand has been properly tucked with the fingers, the flask is filled heaping full of sand. Then by the aid of a rope hanging down from the ceiling, the molder springs up on top of the flask and packs the mold with his feet, the weight of his body giving the right degree of firmness to the sand. Stove-plate molders often pack their flasks in the same way.

The main differences between making up molds for brass and those for iron are due to the three following causes: brass melts at a lower heat; it does not run as fluid as iron; it has about double the shrinkage of iron. For these reasons the sand may be somewhat less porous and still vent sufficiently, if risers are placed to allow for the escape of the air. On bench work the vent wire is not used. The runners for brass should be larger than for iron, and the gates, instead of being broad and shallow, should be more semicircular in section. Pouring molds on end gives the pressure necessary to force a more sluggish metal to take a sharp impression, and the heavy runners shown in the following examples serve to feed the casting as it shrinks. Forms of skimming gates, as explained in an earlier section, are used to good advantage when the work is of a very particular nature.

Cores for brass work are made up as previously described. To give a smoother surface on the small cores, about $\frac{1}{3}$ molding sand is often mixed in with the beach sand of the stock mixture.

Examples of Work. To illustrate more clearly some of the typical methods of brass work, let our first example be a thin flat plate with decoration in low relief on one side.

Place the pattern face down, a little below the center of flask. Sift on facing through a No. 16 sieve, then tuck, fill, and pack, as previously described. Roll over and make a joint. Now cut a half section of the main runners and risers, but do not connect them with the mold at this stage. Dust on parting material from a bag, and ram the other half of the flask just hard enough to stand handling.

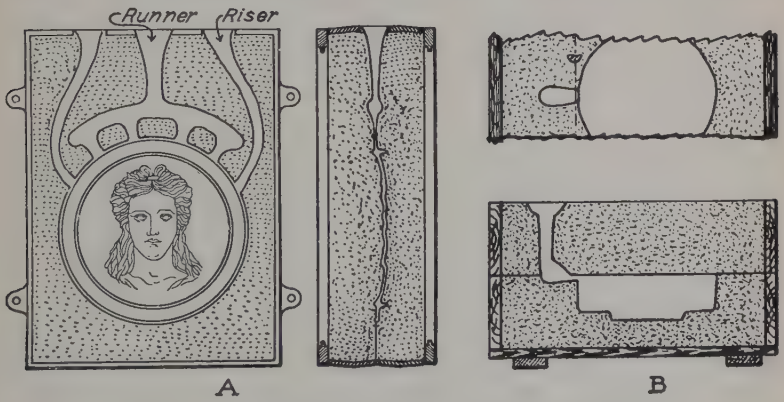


Fig. 177. *A*—Mold for Thin Plate; *B*—Mold for Heavy Plate

Separate the flask; spray the face of the mold with weak molasses water, and dust on it from a bag some finely powdered pumice stone, or any fine strong sand, and over this a little parting dust. Now replace this half over the pattern, and re-ram to the required firmness, and again separate and this time draw the pattern.

The impression of the runners and risers cut in the first half of the mold show as ridges on the second half packed, and serve as guides for cutting the runners to a full round section. Connect the gates in four places, as shown in *A*, Fig. 177. Skin-dry the mold and it is ready to close and pour.

Dusting fine sand on the face of the mold, then reprinting, as it is termed, ensures a very smooth, perfect mold face. Where the mold is not skin-dried, flour is dusted over the face, allowed to stand

TABLE VIII

Crucible Sizes

Number	Holding Capacity (Liquid Measure)			Measurements Outside				Capacity Weight of Water
				Height	Diameter			
					Top	Bilge	Bottom	
	(gallon)	(quart)	(pint)	(inches)	(inches)	(inches)	(inches)	(pounds)
0				2	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{1}{4}$	
0000				3	$2\frac{3}{8}$	$2\frac{1}{2}$	$1\frac{3}{4}$	
6		1		$6\frac{1}{2}$	$5\frac{1}{4}$	$5\frac{1}{8}$	$3\frac{3}{4}$	2.08
12		2		8	$6\frac{1}{4}$	$6\frac{3}{4}$	5	4.16
30	1	1	1	11	$8\frac{5}{8}$	$9\frac{1}{4}$	$6\frac{1}{2}$	11.5
60	3			14	$10\frac{3}{8}$	$11\frac{5}{8}$	8	25
90	4			$15\frac{7}{8}$	$11\frac{1}{2}$	$12\frac{1}{2}$	9	33.3
300	12	2		22	$16\frac{1}{4}$	$17\frac{1}{2}$	$12\frac{1}{2}$	104.

for a short time, and then blown off. This makes a good facing. Cutting the heavy runner over the top of the thin plate ensures a sufficient supply of clean hot metal to the gates under a large enough pressure to force the metal into every detail of the mold before it has time to chill.

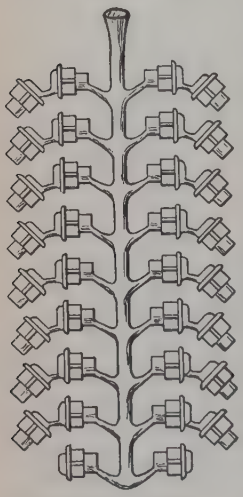


Fig. 178. Duplicated Gated Work

In *B*, Fig. 177, is shown the difference in construction of the gate when a heavier piece is cast with the flask setting horizontally. The gate proper is cut in the drag, but a good feeding head is cut out of the cope side to keep the metal in the riser liquid until the casting has solidified.

Duplication. For duplicating work, the sand match, oil match, or follow board are used, the same as for iron work. Fig. 178 shows a typical set of castings run from the end and made from gated patterns set in an oil match. Steady pins are placed on the gates to facilitate a clean lift.

Melting. *Characteristics.* All alloy metals, and especially zinc and tin, burn if exposed to the air while melting. To prevent this

burning the brass melter endeavors to so control the draft in his furnace that all oxygen entering the gates combines with the fuel, and that the gases which may reach the metal shall contain no free oxygen. For this reason, the ordinary brass furnace is a natural-draft furnace, although a forced draft is often connected below the grates to make combustion independent of atmospheric conditions.

The metal does not come in direct contact with the fuel, but is contained in fire-clay pots called crucibles, which are bedded in the fire. Hard coal or coke is used for fuel. These crucibles, Fig. 179, *A*, are manufactured from a very refractory fire-clay mixture, and are strong and tough, even at a high temperature. They are lifted in and out of the furnace by the tongs shown at *B*, Fig. 179. For the larger sizes a crane is used for hoisting the pot. Crucibles are classed by number, as seen in Table VIII. New crucibles should always be annealed before using, that is, brought very slowly to a low red heat.

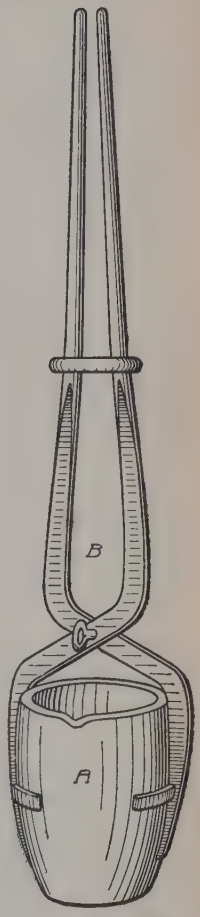


Fig. 179. Crucible and Tongs

Natural-Draft Furnace. Furnaces of this type are usually called brass furnaces, and may be bought on the market made up in single complete units. Fig. 180 illustrates one of a battery of several furnaces connecting with a common flue. The top is on a level with the molding floor. The sketch shows clearly the principles of construction. A cast-iron bottom plate *A*, with a circular opening, carries a shell of boiler plate lined with fire brick. The diameter inside the lining should be 6 inches larger than the crucible to be used. A top plate, with a similar opening, binds the whole together. On one side, below the top, the opening *B*, which may be formed by a cast-iron box, connects with the flue or stack. Two heavy ribs cast on the bottom plate rest on a pair of rails as shown, and these rails are supported by suitable piers of brickwork about 2 feet high, so that ashes may be conveniently removed when the furnace is dumped.

In the space made by the ribs, between the bottom plate and the rails, the grate bars *C* are set. These bars are loose and may be pulled out when it is desired to dump the fire for the day.

Operation. Before starting the fire in preparing to run off a heat, a good plan is to use a half fire brick on which to rest the crucible, or the bottom of a worn-out crucible cut off to the height of 4 inches or 5 inches may be turned upside down and used for this purpose.

Sufficient time and special care should be exercised in placing the metal in a crucible. It is more or less dangerous to jam in the charges, so particular care should be taken to see that they are placed

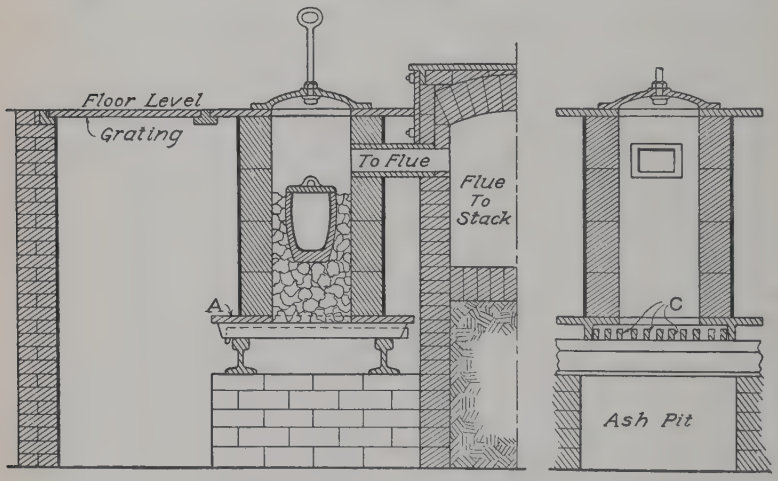


Fig. 180. Natural-Draft Furnace

in the crucible loosely. Graphite is the crucible's principal ingredient; the only expansion possible to a crucible comes from its clay body, hence, if the charges are wedged in a crucible and jammed to fit tight, their expansion, which is much greater than the expansion of the crucible, cracks the latter before the melting point is reached. The crucible should be kept covered, especially for brass.

In melting brass, melt down the copper first, then the scrap. When this is melted, charge the zinc and stir well before lifting the pot. Allow the mixture to come to the proper heat again, then pull the pot, skim off the dross, and stir in the lead if any is called for, just before pouring. In bronze the same method is pursued, but both the

tin and zinc are stirred in after the pot is drawn. In mixing in the zinc in brass, care must be taken to plunge it well under the surface

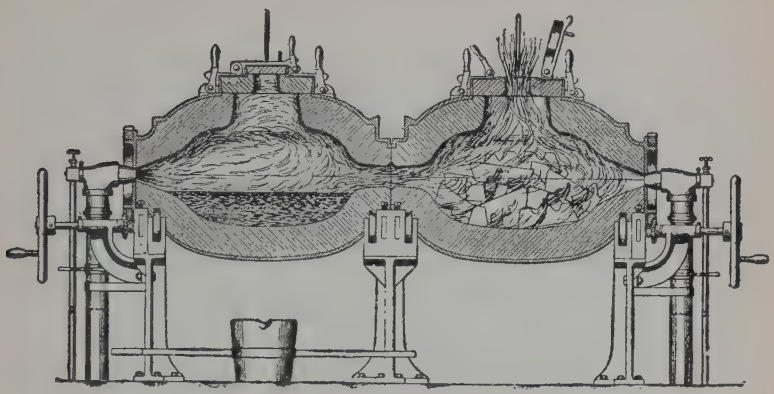


Fig. 181. Section through Oil Furnace

of the copper with long handled pick-up tongs, and to hold the piece down with the stirring bar until it has melted.

Where a large casting requires more metal than can be melted in a single crucible, several furnaces must be used and the contents of their various crucibles assembled into one large pouring ladle just before pouring.

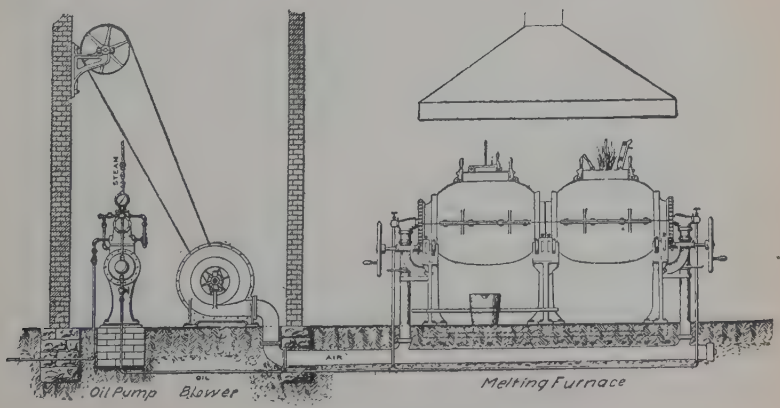


Fig. 182. General Views of Oil Furnace

Gas or Oil Furnace. With the development of natural-gas and crude-oil burners for commercial heating, several good furnaces have been designed in which a large quantity of metal can be melted at

one time. Fig. 181 shows a furnace of this character in section. This type has tandem melting chambers with burners at the end, which may be used separately or both together. The waste gases from the

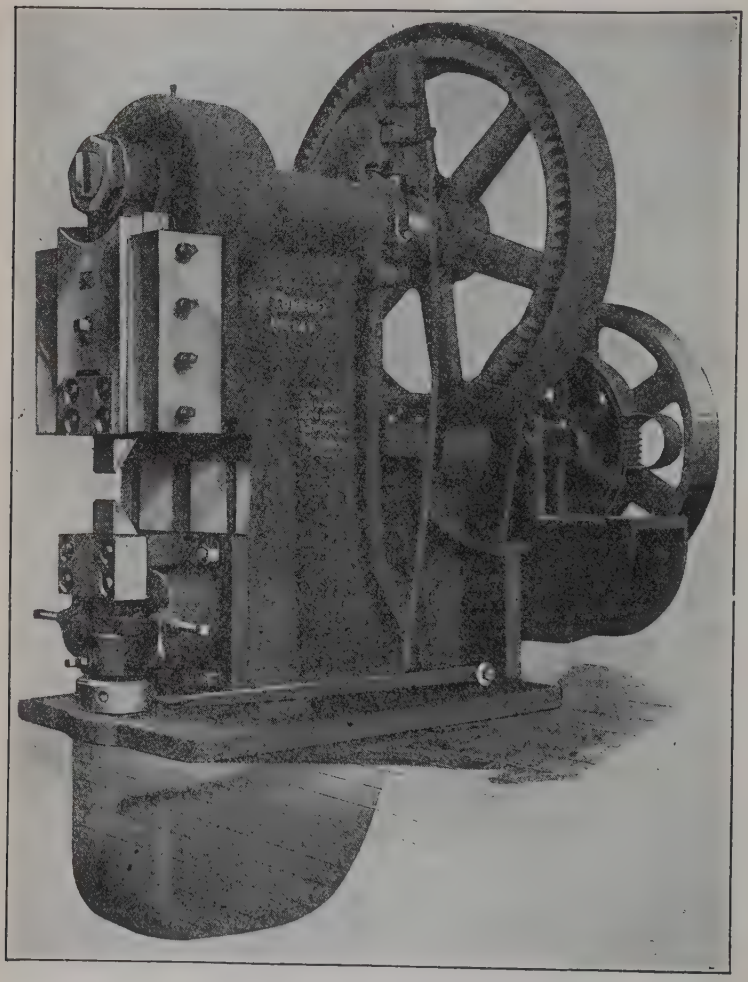


Fig. 183. Sprue Trimmer
Courtesy of Toledo Machine and Tool Company, Toledo, Ohio

bath of liquid metal are used to heat up a fresh charge in the other chamber. The metal is charged and poured from the openings at the top of the furnace. Each chamber may be revolved separately, to

empty the furnace when the charge is melted. Fig. 182 shows the general arrangement of the oil feed pump and blower for these melting furnaces. The flame plays directly on to the metal. The oil pressure should remain constant at about 5 pounds per square inch. But the air pressure is regulated to vary the intensity of the heat as desired.

The pouring ladle must be well heated before using. This is done with a special gas burner, or, when crucibles are used, they are often heated by means of a small fire in an ordinary furnace.

Fig. 184. Dipping Basket

Different sizes of furnaces are built to melt from 250 to 2000 pounds of metal at a heat. Twelve or fourteen heats a day can be run. The saving is approximately 50 per cent in time, and is also very considerable in expense, over ordinary crucible furnaces of equal capacity.

Cleaning. When the castings are taken from the sand they should be rapped smartly to free all loose sand, then, if machining is to be done on them, they should be plunged, while hot, into water. This softens the castings. This method is used also to blow out cores from small work.

Since brass does not burn into the sand as much as iron, the small castings in many shops are brushed clean, before being cut from the gates, by means of a circular scratch brush mounted on a spindle similar to a polishing wheel.

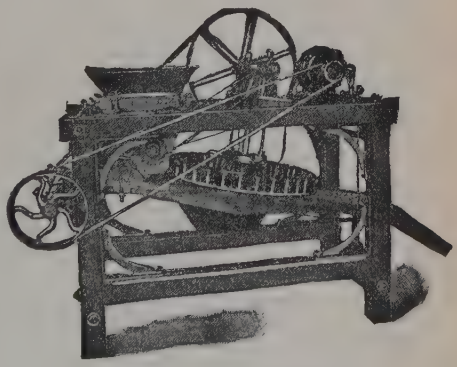


Fig. 185. Magnetic Separator

A sprue-trimmer, shown in Fig. 183, is part of the equipment of a brass foundry. These machines are made to operate by foot as shown, or by power. With them the castings are cut neatly and quickly from the runners.

Pickling. A good method of cleaning brass and bronze is by pickling. Make a mixture of 2 parts common nitric acid and 1 part

sulphuric acid, in a stone jar. Place the piece to be cleaned in a stone dipping basket, Fig. 184, and dip once into the acid, then wash off in clean water, and dry in sawdust.

Chip Separation. In many cases, brass chips and filings are turned back to the foundry to be remelted. The smallest portions of steel or iron in these would prevent their being used in this way, as they make extremely hard spots in the castings.

Fig. 185 shows a magnetic separator which effectively removes all steel and iron chips. The brass chips and sweepings from the machine shop are placed in the hopper of this machine. They are caused to be spread out on one side of a slowly revolving brass covered drum. Inside of this brass shell are strong magnets which hold to their surfaces the steel and iron chips, while the brass chips drop off into a tote box. A stiff brush at the back of the cylinder removes the iron chips, and they drop into a separate box.

SHOP MANAGEMENT

PLANT ARRANGEMENT

Governing Factors. The success of a foundry depends upon the ability of its managers to promptly turn out castings which meet the requirements demanded of them, at the lowest possible cost commensurate with the quality of the work. In this article we wish to direct the attention of students to some features in the way of equipment and management which aid in accomplishing these results.

The most important processes in the foundry are the following: melting metal, making molds, and pouring them. Much of the work necessary in preparing for these processes consists in handling heavy materials such as coke, iron, sand, etc. To reduce this handling to its lowest limits, as to distances, number of re-handlings, and methods of conveyance, are problems to be considered in the plan of the shop as a whole.

TYPICAL FOUNDRY

General Plan. To briefly illustrate some of the points to be brought out, let us consider the plan of the shop shown in Fig. 186, and its sectional elevation shown in Fig. 187.

Building. The building is of steel construction, and the columns supporting the roof trusses serve also to carry the tracks for the overhead traveling cranes.

The outer walls should be filled in with some good weather-resisting material, of which there is nothing better than brick. These walls should be of good height and have a sufficient window area to supply light well in toward the middle of the shop.

Ventilation. The method of heating and ventilating best adapted for a foundry is the indirect fan system. One or more large

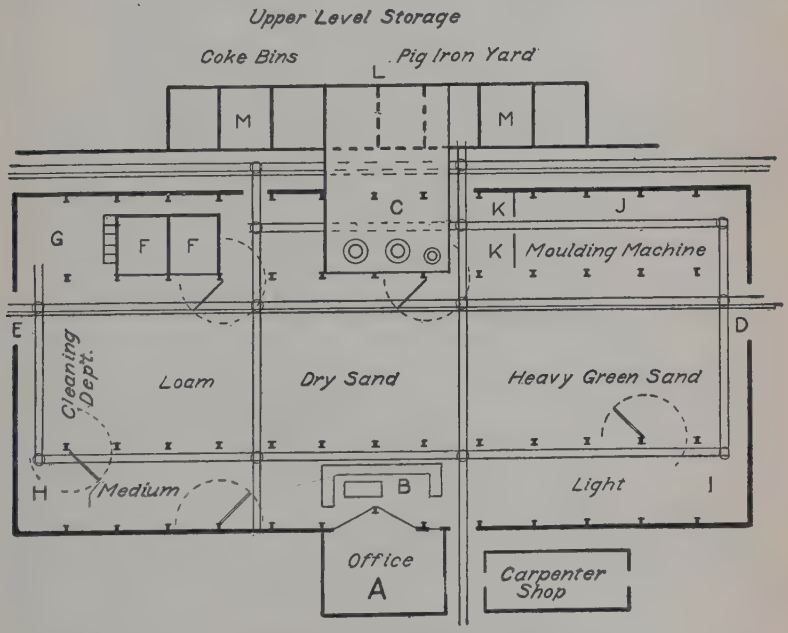


Fig. 186. Typical Plan of Foundry

fans, situated generally toward the ends of the shop, draw fresh air in through a compact system of steam coils, and, by means of overhead piping, deliver it to all portions of the shop. The impure gases are carried off through ventilators in the clearstory at the top of the roof.

Floor. The floor of the foundry should consist of molding sand, the depth of the sand floor varying with the class of work to be done. If the natural soil of the grounds is open and porous, a thickness of 3 or 4 inches of clay, well rolled down, should be put in underneath

the sand floor. This will help greatly in keeping the molding floor in good condition, as it prevents the moisture draining out of the sand.

Shop Office. The foundry office should be located at such a point that the foreman can command a view of the whole shop. It should be convenient to the different departments and at the same time be protected as far as possible from dust. The office room, shown in Fig. 186 at *A*, is built on the outside of the main building, but has a large bay window which projects a few feet into the shop from which all corners of the foundry can be seen.

Pattern Room. A space *B*, having suitable low tables and shelving, is reserved near the office for the temporary storing of patterns in daily use. This brings them directly under the attention of the foreman and his assistants who can readily check the patterns as they come in and quickly find those requiring prompt attention.

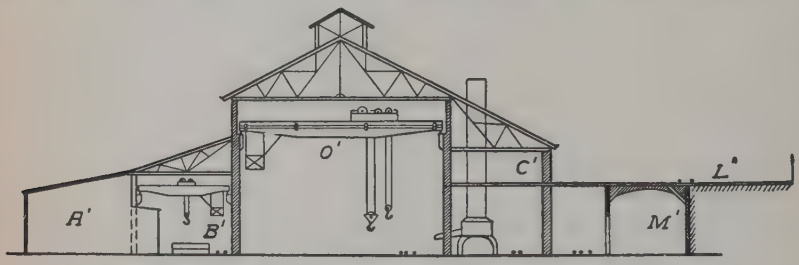


Fig. 187. Typical Elevation of Foundry

Cupolas. At *C* are shown the cupolas, directly opposite the foreman's office, and so situated that all of the molding floors may be served as quickly as possible without interfering one with the other.

In large foundries there are two or more cupolas, to admit of different mixtures being melted simultaneously. Often a comparatively small cupola is installed near the floor for light work for the service of that floor alone.

The blowers should be placed near the cupolas, avoiding long connecting wind pipes. The application of electric motors removes the necessity of concentrating the power at one point in the shop.

Molding Divisions. *Heavy Work.* The main bay of the foundry is devoted to the heaviest work and is served by at least two overhead cranes.

The heavy green-sand castings are made at one end so that the flasks for this work may be stored in yards near by and be brought in through the door *D*. These molds are made up farthest from the cleaning shed, because only the castings themselves need be transferred there.

The flasks and rigging for the dry-sand and loam molds should be brought in through the opposite door *E*. The loam work, as a rule, is the most bulky to handle and should be nearest the cleaning

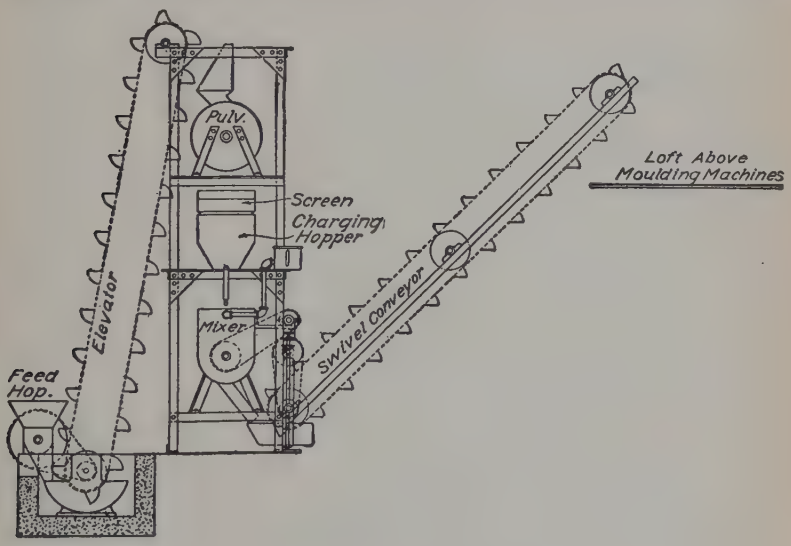


Fig. 188. Automatic Sand Mixer

sheds so that it need not be carried across the other floors. Both dry-sand and loam floors are convenient to the large ovens *F*.

Core Shop. The core shop is situated in the side bay at *G*, to make it convenient to swing the large cores on to the buggies to be run into the large ovens. A jib crane near the corner of these ovens makes the men working on such cores independent of the traveling crane. The ovens for small cores are built along the side of the large ovens and utilize the same stoke hole, ash pit, and stack.

Light Work. Distributed through the side bays also are the medium-work floor *H*, the light-work floor *I*, and the molding-machine floor *J*. This ensures a supply of good light necessary to the smaller details of this class of work.

Machines. The molding machines are placed on that side of the shop near the sand storage sheds, to allow for handling the sand by means of belt conveyors with hoppers above the machines, an illustration of which is shown in Fig. 188.

The sand-mixing space is in the side bay near the cupolas at *K*, and is furnished with power from independent motors or from a jack shaft leading from the blower room. This position affords direct access to the sand bins. The raw material after being mixed and tempered is delivered by barrow or sand car direct to the various floors. The mixers might be installed in one of the storage vaults across the roadway.

Materials. *Unloading.* The quickest means of unloading either wagon or carload lots of material is by dumping, where the material can be so handled. One of two things is necessary to accomplish this: either the storage bins must be placed in a basement underneath the roadbed; or the roadway must be run up an incline over the top of the bins. The former method is more frequently met with in the crowded condition of the large cities, but the latter is preferable because less time is consumed in running material up an incline in large quantities than is required to hoist small quantities more frequently from a basement.

Storage. At *L* and *L'*, Figs. 186 and 187, are shown the storage yards for pig iron and coke; these are on a level with the charging platform of the cupola, *C* and *C'*, and the materials can be loaded on cars and pushed directly to the charging door. In some modern shops these push cars are built so that their load may be dumped as a whole into the cupola.

The storage for core-oven fuel, sands, and clay, is shown at *MM*, in bins built underneath the tracks and on a level with the foundry floor. These bins should be arranged to open on top, with a chute under the track and a trap at the side, so that coal or sand may either be dumped or shoveled directly into them.

Handling Systems. *Tracks.* In the largest shops a standard-gage track should run directly through the main foundry, and there should be also similar tracks through the roadway next the cupola bay for convenience in removing the dump. The track over the storage bins has been mentioned.

Two methods of transferring material between departments within the shop, aside from the cranes, are the overhead-trolley

system, Fig. 189, and the narrow-gage industrial railway. The former is of advantage in manufacturing plants where the loads to be transferred are nearly uniform in weight and frequency of handling. This system leaves gangways smooth and free from obstructions. For general work, however, the industrial railways are more frequently installed. These serve all floors to deliver flasks, sand, or iron, and to remove castings.

Cranes. Of the many styles of overhead traveling cranes that are on the market, those using electricity as the motive power are undoubtedly the most serviceable. The cranes in the main foundry indicated at *O'*, Fig. 187, should have two hoisting drums on the carriage; one for such light work as handling flasks, rigging, and patterns; the other for the heavy work on the large ladles and castings.

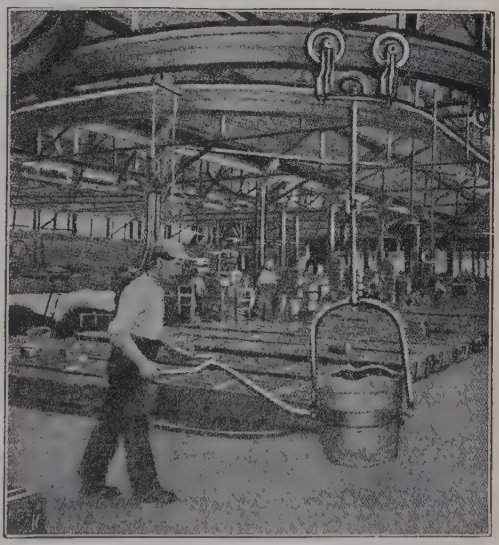


Fig. 189. Overhead Track and Trolley

Small jib cranes furnished with a 2- to 4-ton air or electric hoist placed on the side of a man's floor make it possible for the molder and helper to handle work of considerable size by themselves, and prevent loss of time from waiting for the overhead crane.

The method of distributing the melted metal varies with the class of work made. In shops doing general jobbing work, the ladles for pouring the largest work are carried from the cupola directly by the overhead cranes.

Bay Floor. For serving the floors in the bays one of the systems mentioned above is generally used. The metal is conveyed to the floor in a large ladle and from this smaller ones are filled and carried by hand or by a small crane to the molds.

Cleaning Department. The cleaning department should be situated at one end of the shop near *E*, Fig. 186, or in a shed extension

to the foundry proper. It requires space to pile the castings as they are brought from the floors with sufficient room for the men to begin work on these piles. As a rule, the smaller castings are first collected and put through the tumbling barrels, then the medium work is cleaned by hand or by sand blast; this leaves room for work around the largest pieces. As soon as castings are cleaned they are weighed and shipped to the customer, store house, or to the department which does the next operation upon them.

PERFORMANCE

LABOR

Division. The division of labor in a foundry is briefly as follows:

Superintendent. The superintendent is responsible for the operation of the foundry as a whole. He hires the men and oversees the purchase of materials and supplies, having under him clerks who keep track of the details of this work. Some of the things to which he gives personal attention are: In consultation with his foreman he gives personal attention to the receipt of the most important patterns; decides how they shall be molded; on what floor and with what mixture they shall be poured. He devises ways and means of increasing the productiveness of his shop.

Foreman. The foreman or his assistants must be in the shop a sufficient time before work begins for the day to see that each molder has work laid out for him, and must keep the men supplied with work through the day. He estimates the amount of the charge for the day and directs the melter as to mixtures.

It is the duty of the foreman and his assistants to give directions to the apprentice boys and to see that these directions are carried out to the best of the boys' ability.

Molders. The molders should give their entire time to making up molds. On floor work they are usually given a helper who carries flasks, cores, chaplets, etc., and does the heavier work when handling the sand. When the molds are poured and his flasks stripped off the molder is through for the day.

Laborers. Most modern shops employ a night gang of laborers to put the shop in proper shape for the molders to start their special work immediately when the whistle blows in the morning. These men remove the castings from the sand and transfer them to the

cleaning shed. They pick out all bars and gaggers used in the molds and stow them in place. They temper and cut the sand and dig any pits necessary for bedding in work.

SAFETY FIRST

Accident Prevention. While it may be an impossibility to wholly prevent accidents in and about the foundry, much has been accomplished in that line. Mechanical safeguards are now in pretty general use in modern foundries. It is only the out-of-date shop which is conspicuous for neglect in providing them.

Personal Factor. Only some of the more important items regarding safety are called to the reader's attention, and perhaps the most important one of all is to teach the workman to think *safety first.* As an example, in a foundry employing 850 men there were, during a period of 6 months, 57 accidents involving loss of time. Not one of these was due to the lack of mechanical safeguards; all were results of carelessness on the part of the injured, or of negligence by their fellow workmen.

Clothing. A large percentage of accidents in the foundry are in the nature of burns from hot metal, and again by far the greater part of these are below the knee. This shows the practical necessity for a legging of some material which would resist the hot metal. All employes in the foundry who come in contact in any manner with the work of pouring, or of shaking out flasks after pouring, when the hot sand may be just as dangerous as the molten metal, should be compelled to wear the foundry or congress shoe.

Shop Equipment. There should be frequent inspection of all foundry rigging, such as crane hooks, chains, and ladle shanks, also great care should be used under the cupola and tapping spout, as any excess of moisture, were molten metal to be spilled upon it, would cause explosions and probably seriously injure someone.

In the cleaning room, protection for the eyes from flying chips of metal is important; so, also, are guards over grinding wheels which should be equipped with an efficient exhaust to care for dust.

While there are many more things which might be mentioned regarding safety, as applied to foundry practice, those already mentioned should be sufficient to cause the student to *think* safety, to put his thoughts in practice and to teach others to do likewise.

PHYSICAL RESULTS

Checking. The methods of mixing iron by analysis have been previously dealt with, but these mixtures must be checked by physical tests on the resulting castings. Two systems of checking are now in more or less general use throughout the United States.

Keep's Mechanical Analysis. A very complete system of regulating mixtures, termed by the inventor *Mechanical Analysis* has been devised by W. J. Keep, of Detroit, Michigan, who has had long experience in this subject. In Fig. 190, *A* shows a follow board arranged with patterns and yokes. The test bars are $\frac{1}{2}$ inch square and 12 inches long. They are cast in green sand with their ends chilled against the faces of the cast-iron yokes, shown in the cut. Three molds should be cast each heat, and the test bars allowed to cool in the molds.

Silicon and Shrinkage. The analysis is based on the fact that silicon is the most important variable chemical element in cast iron,

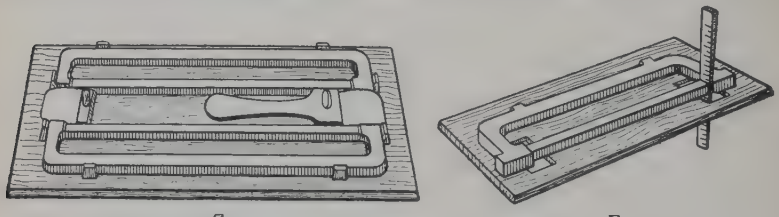


Fig. 190. *A*—Keep's Test-Bar Pattern; *B*—Measuring Shrinkage

and that shrinkage in castings is inversely proportionate to the silicon in the mixture.

The first test, as shown at *B*, Fig. 190, is to replace each bar in the same yoke in which it was cast and by means of a specially graduated taper scale to ascertain accurately the amount of shrinkage.

The shrinkage of the bars when the castings prove satisfactory, should be considered the standard for that class of work for that shop. If at any time the shrinkage is greater than the standard, increase the silicon by using more soft pig; if it is less, decrease silicon by using more scrap or cheaper iron.

Chilled Depth. The depth of chill on the castings is measured after chipping off a piece from the end of the bar.

Transverse Strength. The third test is to obtain the transverse strength of each bar. This is done on a special testing machine

which gives a graphical record of the deflection and the ultimate breaking load. These dead loads will vary with different mixtures approximately from 340 to 500 pounds.

Deductions. Quoting from Mr. Keep's circular:

With high shrinkage and high strength of a $\frac{1}{2}$-inch square test bar, heavy castings will be strong but small castings may be brittle.

With low shrinkage and high strength, large castings will be weak and small castings will be strong.

With uniform shrinkage, an increase in the strength of a $\frac{1}{2}$-inch square test bar will increase the strength of all castings proportionately.

Arbitration-Bar Tests. The other form of tests was devised by a committee of the American Foundrymen's Association, and is recommended in the Proposed Standard Specifications for Gray-Iron Castings by the American Society for Testing Materials.

Test Bar. The test bar specified is $1\frac{1}{4}$ inches in diameter and 15 inches long, and is known as the *arbitration bar.*

The tensile test is not recommended, but, if called for, a special threaded test piece is turned down from the arbitration bar, and has a test section 0.8 inch in diameter and 1 inch between shoulders.

The transverse test is made with supports 12 inches apart.

Fig. 191 shows a sketch of the patterns for these bars. Two bars are rammed in a flask and poured on end. The small prints on the two bar patterns project into the cope and are connected by one pouring basin. A special green-sand mixture is specified for making these molds; the molds are to be baked before pouring, and the bars allowed to remain in the sand until cold.

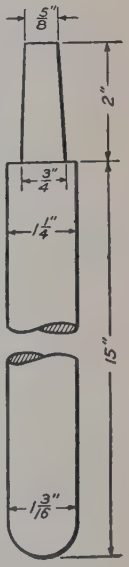


Fig. 191. Pattern for Arbitration Bar

Specifications. Table IX shows the specified requirements; in this connection castings are distinguished as follows:

Unless furnace iron is specified, all gray castings are understood to be made by the cupola process.

Light castings are those having any section less than $\frac{1}{2}$ inch.

Heavy castings have no section less than 2 inches.

Medium castings are those not included in the above.

TABLE IX

Arbitration-Bar Standards

Grade of Castings	Chemical Properties	Physical Properties	
	Sulphur Content High Limit (per cent)	Transverse Test* Minimum Load (lb.)	Tensile Strength Low Limit (lb. per sq. in.)
Light	0.08	2500	18,000
Medium	0.10	2900	21,000
Heavy	0.12	3300	24,000

PRACTICAL DATA

Using Percentage

(1) To find the percentage of any number when the rate per cent is given: Multiply the number by the rate per cent and set the decimal point two places to the left.

Example: Find 7.5 per cent of 35. $35 \times 7.5 = 262.5$; decimal point moved two places to the left gives Ans. 2.625

(2) To find what rate per cent one number is of another: Add two ciphers to the percentage and divide by the number on which the percentage is reckoned.

Example: What per cent of 75 tons is 9 tons? $900 \div 75 = 12$.

Ans. 12 per cent

(3) To find a number when the rate per cent and the percentage are known: Add two ciphers to the percentage and divide by the rate per cent.

Example: If 68 pounds is 15 per cent of the entire charge, how many pounds in the total charge? Ans. $6800 \div 15 = 453.33$ pounds

(4) To find what number is a certain per cent more or less than a given number: (*a*) When the given number is more than the required number, add two ciphers to the number and divide by 100 plus the rate per cent.

Example: 465 is 35 per cent more than what number?

Ans. $46500 \div (100+35) 135 = 344.4$

(*b*) When the given number is less than the required number add two ciphers to the number and divide by 100 minus the rate per cent.

*In no case, shall the deflection be under 0.10 of an inch.

Storage Data

Square Box Measure

Size (inches)	Capacity
24 ×16 ×28	1 barrel
16 ×16¾ × 8	1 bushel
8¼ × 8¼ × 4	1 gallon
4 × 4¼ × 4	1 quart

Molding Material Weights

Material	Amount (cu. ft.)	Weight (ton)
River sand	21	1
Pit sand	22	1
Stiff clay	28	1

Example. 526 is 23 per cent less than what number?

Ans. $52600 \div (100-23) = 52600 \div 77 = 683.116$

Mensuration

Circumference of a circle	= diameter × 3.1416
Area of a square or rectangle	= base side × height
Area of a triangle	= base × ½ × perpendicular height
Area of a circle	= diameter squared × .7854
Convex surface of a cylinder	= circumference × height
Convex surface of a sphere	= circumference × diameter
Contents of a rectangular solid	= area of base × height
Contents of a cylinder	= area of base circle × height
Contents of a sphere	= cube of diameter × .5236
One side of square having same area as given circle	= diameter × .8862 or circumference × .2821

Conversion Factors

Inches	×	0.08333	= feet
Square inches	×	0.00695	= sq. feet
Cubic inches	×	0.00058	= cu. feet
Cubic inches	×	0.004329	= U. S. gallons
Cubic feet	×	1728	= cu. inches
Cubic yards	×	27	= cu. feet
U. S. gallons of water	×	8.33	= pounds
U. S. gallons of water	×	231.00	= cu. inches
Pounds of water	×	27.72	= cu. inches
Ounces of water	×	1.735	= cu. inches

Circular Areas and Circumferences

Diameter	Area	Circumference	Diameter	Area	Circumference	Diameter	Area	Circumference	Diameter	Area	Circumference
1/16	0.0123	.3926	10	78.54	31.41	30	706.86	94.24	65	3318.3	204.2
1/8	0.0491	.7854	1/2	86.59	32.98	31	754.76	97.38	66	3421.2	207.3
3/16	0.1104	1.178	11	95.03	34.55	32	804.24	100.5	67	3525.6	210.4
1/4	0.1963	1.570	1/2	103.86	36.12	33	855.30	103.6	68	3631.6	213.6
5/16	0.3067	1.963	12	113.09	37.69	34	907.92	106.8	69	3739.2	216.7
3/8	0.4417	2.356	1/2	122.71	39.27	35	962.11	109.9	70	3848.4	219.9
7/16	0.6013	2.748	13	132.73	40.85	36	1017.8	113.0	71	3959.2	223.0
1	0.7854	3.141	1/2	143.13	42.41	37	1075.2	116.2	72	4071.5	226.1
1/16	0.9940	3.534	14	153.93	43.98	38	1134.1	119.3	73	4185.3	229.3
1/8	1.227	3.927	1/2	165.13	45.55	39	1194.5	122.5	74	4300.8	232.4
3/16	1.484	4.319	15	176.71	47.12	40	1256.6	125.6	75	4417.8	235.6
1/4	1.767	4.713	1/2	188.69	48.69	41	1320.2	128.8	76	4536.4	238.7
5/16	2.078	5.105	16	201.06	50.26	42	1385.4	131.9	77	4656.0	241.9
3/8	2.405	5.497	1/2	213.82	51.83	43	1452.2	135.0	78	4778.3	245.0
7/16	2.761	5.890	17	226.98	53.40	44	1520.5	138.2	79	4901.6	248.1
2	3.141	6.283	1/2	240.52	54.97	45	1590.4	141.3	80	5026.5	251.3
1/16	3.976	7.068	18	254.46	56.54	46	1661.9	144.5	81	5153.0	254.4
1/8	4.908	7.854	1/2	268.80	58.11	47	1734.9	147.6	82	5281.0	257.6
3/16	5.939	8.639	19	283.52	59.69	48	1809.5	150.7	83	5410.6	260.7
3	7.068	9.424	1/2	298.64	61.26	49	1885.7	153.9	84	5541.7	263.8
1/4	8.295	10.21	20	314.16	62.83	50	1963.5	157.0	85	5674.5	267.0
1/2	9.621	10.99	1/2	330.06	64.40	51	2042.8	160.2	86	5808.8	270.1
3/4	11.044	11.78	21	346.36	65.97	52	2123.7	163.3	87	5944.6	273.3
4	12.566	12.56	1/2	363.05	67.54	53	2206.1	166.5	88	6082.1	276.4
1/2	15.904	14.13	22	380.13	69.11	54	2290.2	169.6	89	6221.1	270.6
5	19.635	15.70	1/2	397.60	70.68	55	2375.8	172.7	90	6361.7	282.7
1/2	23.758	17.27	23	415.47	72.25	56	2463.0	175.9	91	6503.8	285.8
6	28.274	18.84	1/2	433.73	73.82	57	2551.7	179.0	92	6647.6	289.0
1/2	33.183	20.42	24	452.39	75.39	58	2642.0	182.2	93	6792.9	292.1
7	38.484	21.99	1/2	471.43	76.96	59	2733.9	185.3	94	6939.7	295.3
1/2	44.178	23.56	25	490.87	78.54	60	2827.4	188.4	95	7088.2	298.4
8	50.265	25.13	26	530.93	81.68	61	2922.4	191.6	96	7238.2	301.5
1/2	56.745	26.70	27	572.55	84.82	62	3019.0	194.7	97	7389.8	304.7
9	63.617	28.27	28	615.75	87.96	63	3117.2	197.9	98	7542.9	307.8
1/2	70.882	29.84	29	660.52	91.10	64	3216.9	201.0	99	7697.7	311.0

Weight Calculation

Weight of round iron per foot = Diameter (quarter inches) squared $\times 0.1666$
Weight of flat iron per foot = Width $\times$ thickness $\times 3.333$
Weight of plates per sq. ft. = 5 pounds for each $\frac{1}{8}$ inch in thickness
Weight of chain = Diameter squared $\times 10.7$ (approximate)
Safe load (pounds) for chain = Bar diameter (quarter inches) squared $\times$ 2000

To compute weight of metal from weight of pattern, with no allowance for cores or runners, multiply as follows:

Multiplication Factors

White Pine	Mahogany	Result
16.7	10.7	Cast iron
18	12.2	Brass
23	15.	Lead
15	9.	Tin
16	10.4	Zinc

Weight of brass pattern $\times .9$ = weight of iron casting, approximately.

Specific Gravities and Weights of Metals

Material	Specific Gravity	Weight per Cubic Inch (pounds)
Water, at 39.1° F.	1.	.036
Aluminum	2.6	.094
Antimony, cast 6.64 to 6.74	6.7	.237
Bismuth	9.74	.352
Brass, cast 7.8 to 8.4	8.1	.30
Bronze 8.4 to 8.6	8.5	.305
Copper, cast 8.6 to 8.8	8.7	.32
Gold, pure, 24 carat	19.25	.70
Iron, cast 6.9 to 7.4	7.21	.263
Iron, wrought 7.6 to 7.9	7.77	.281
Lead	11.4	.41
Mercury, at 60° F.	13.58	.49
Platinum 21. to 22.	21.5	.775
Silver	10.5	.386
Steel, average	7.8	.283
Spelter or zinc 6.8 to 7.2	7.	.26
Tin, cast 7.2 to 7.5	7.35	.262

Pressure In Molds

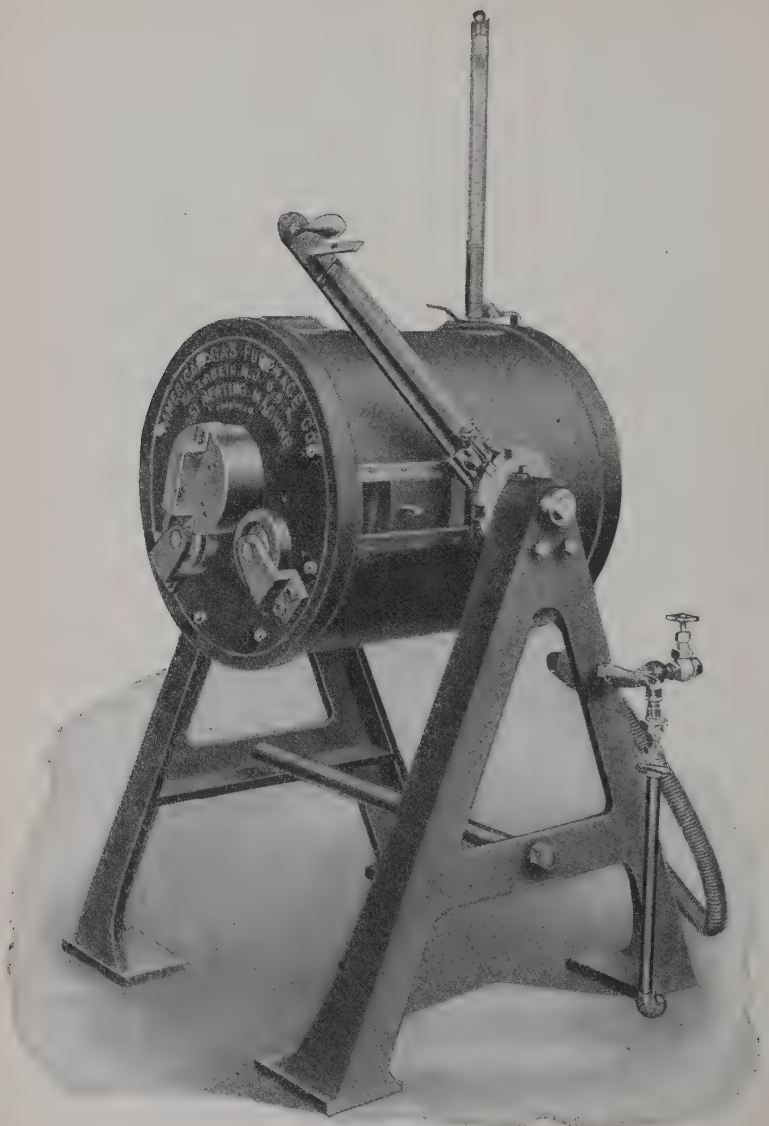
Depth (ft.)	Depth (in.)	Pounds (per sq. in.)	Depth (ft.)	Depth (in.)	Pounds (per sq. in.)	Depth (ft.)	Depth (in.)	Pounds (per sq. in.)
	1	.26		19	4.94	3	6	10.92
	2	.52		20	5.20	4		12.48
	3	.78		21	5.46	4	6	14.04
	4	1.04		22	5.72	5		15.60
	5	1.30		23	5.98	5	6	17.16
	6	1.56	2	00	6.24	6		18.72
	7	1.82		25	6.50	6	6	20.28
	8	2.08		26	6.76	7		21.84
	9	2.34		27	7.02	7	6	23.40
	10	2.60		28	7.28	8		24.96
	11	2.86		29	7.54	8	6	26.52
1	00	3.12	2	6	7.80	9		28.08
	13	3.38		31	8.06	9	6	29.64
	14	3.64		32	8.32	10		31.20
	15	3.90		33	8.58	10	6	32.76
	16	4.16		34	8.84	11		34.32
	17	4.42		35	9.10	11	6	35.88
1	6	4.68	3	00	9.36	12		37.44

To find the total lifting pressure on the cope, multiply the pressure per square inch at a given depth below the pouring basin by the area (square inches) of the surface acted against. The result is in pounds.

Temperatures*

Connection		Heat (Degrees Fahrenheit)
Core ovens		250 to 450
Bright iron becomes	yellow	435
	purple	500
	indigo	550
	gray	750
Tin melts		445
Mercury boils		660
Lead melts		612
Zinc melts		775
Silver melts		1775
Copper melts		1885
Gold melts		1900
Iron bar red in	a dark room, just visible	950
	ordinary office	1075
	daylight, open air	1450
Cast iron melts	white	2075
	gray	2230
Steel melts		2750
Annealing malleable iron		1600 to 1750

*From late scientific investigations.



GAS HEATING FURNACE

Courtesy of American Gas Furnace Company, New York City

FORGING

PART I

MECHANICAL DETAILS

MATERIALS AND EQUIPMENT

Forging Materials. Forging in general treats of the hammering, working, or forming of heated metals. The materials upon which forging or blacksmithing is done, are wrought iron and steel. As explained in "Metallurgy", wrought iron is an iron from which the silicon, phosphorus, and most of the carbon has been removed. Steel usually contains some of the impurities that are characteristic of cast iron with the marked peculiarity of holding a varying percentage of carbon. Mild steels are so called on account of the small amount of carbon which they contain. As the percentage of carbon increases, it becomes more difficult to weld the metal. Greater care must also be used in heating lest the metal be burned and its strength destroyed. Until recently all heavy forgings involving welding were made of wrought iron, but now it is customary to make most forgings of mild steel, particularly large ones, although wrought iron is somewhat more satisfactory where a great amount of welding is required.

Classes. These metals may be roughly divided into three general classes, although the division line may not be sharply drawn between any two classes, as follows: (1) wrought iron; (2) machine steel; and (3) tool steel. The characteristics and method of manufacture of the metals are described in "Metallurgy." A rough distinction such as a blacksmith would use is about as follows: Wrought iron has a fibrous structure with stringy streaks of slag running lengthwise of the bar, giving it a decided fiber similar to wood. Machine steel, more properly described as mild steel, or sometimes called soft steel, has much the same properties as wrought iron excepting that it lacks the fiber and is somewhat stronger. Tool steel differs from the other two materials in the fact that by suddenly cooling from a high heat it may be made very hard, or hardens, to use the technical term. Wrought iron or machine steel are not hardened by the same treat-

ment. Tool steel is practically the same thing as wrought iron or machine steel with a small percentage of carbon added. In fact, either of the two metals may be turned into tool steel by the addition of carbon. This principle is used in casehardening. Norway iron or Swedish iron is a grade of very pure wrought iron containing little slag. It is more expensive than ordinary wrought iron. Refined iron is a grade of wrought iron not as good as Norway iron but better than ordinary iron. Norway iron costs about twice as much as machine steel, which is somewhat cheaper than wrought iron of almost any grade. Machine steel, made by both the open-hearth and Bessemer processes, is used for forging.

Sizes of Stock. Material from which forgings are ordinarily made comes to the forge shop in the shape of bars having uniform sections throughout; generally round, square, or rectangular in section, and varying from $\frac{1}{8}$ inch thick to 18 inches square. Heavier sizes may be had to order. Bars are ordinarily 12 to 20 feet in length. Thin stuff, $\frac{1}{8}$ inch or less in thickness, usually comes in strips of about 40 feet. This may be had from stock up to 6 or 8 inches wide. Tool steel also comes in bars generally about 6 or 8 feet long. The ordinary sizes of tool-steel stock are known as *base sizes* and the price is fixed on these base sizes. Stock of a larger or smaller size than the base sizes is generally charged for at an increase in price. Thus inch-square tool steel, which is a base size, is worth in certain grades about 14 cents a pound. Steel of exactly the same grade and character, $\frac{3}{16}$ of an inch square, costs about 18 cents.

Classification of Equipment. The outfit of a forge shop consists in general of the heating apparatus—the forge, furnaces, etc.; and the handling equipment—the anvil, the various tools, and the machines for shaping and working.

HEATING APPARATUS

Forges. While forges or fires are of many shapes and sizes, the principles of their construction remain the same. An ordinary blacksmith forge is a fireplace in the bottom of which there is a tuyere for admitting a blast of air to blow the fire. Where the air blast is furnished by a hand bellows, the pipe leading therefrom to the tuyere is open throughout. Where a power-driven blower furnishes the blast, there is a valve in the pipe for regulating it.

The usual form of tuyere consists of a single blast pipe, opening into the bottom of the fire pit. This may be a simple nozzle as in Fig. 1, with the blast regulated by a damper in the pipe; or, it may have a regulator at the mouth of the tuyere as shown. Sometimes the tuyere has several openings, and is then in the form of a grate. Whatever its form, it should be possible to clean it from below, in order that coal and clinkers falling into it may be removed.

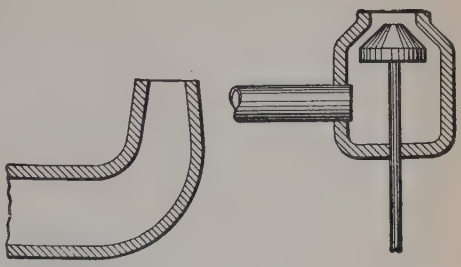


Fig. 1. Tuyere

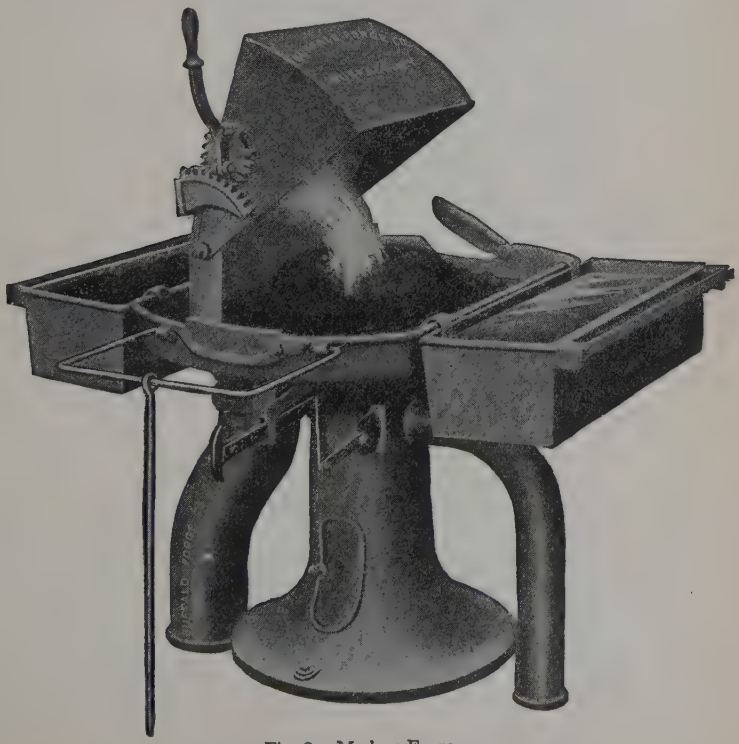


Fig. 2. Modern Forge
Courtesy of Buffalo Forge Company, Buffalo, New York

A modern type of forge is shown in Fig. 2. This is provided with a hood for carrying off the smoke. The pipe connected to the

hood extends downward to an underground flue leading to an exhaust fan which draws out the air. The blast pipe is also underground, and a small pipe leads upward to the tuyere, the amount of blast admitted to the fire being regulated by a slide in this pipe. This system of underground piping is known as the down-draft system.

In some shops no provision is made for carrying off the smoke, while in others hoods are placed above the forges and connected to

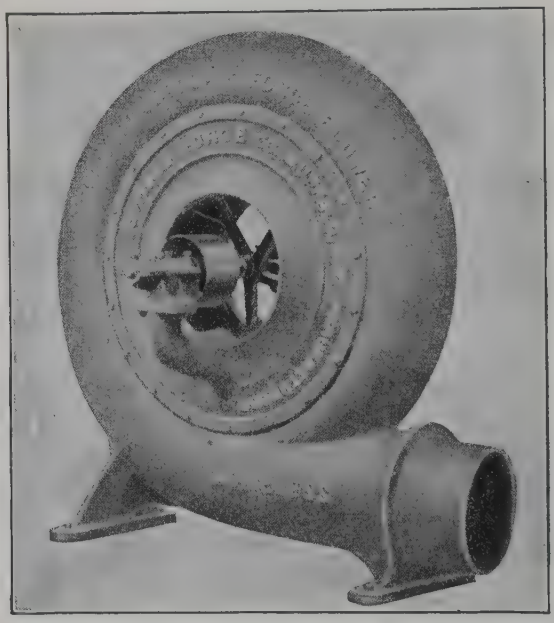


Fig. 3. Motor-Driven Exhauster or Blower
Courtesy of Buffalo Forge Company, Buffalo, New York

overhead pipes, which may be either connected to an exhaust fan or led directly to the roof. The down-draft system is the more modern and generally the best.

Blast. The blast is furnished to the fires of a blacksmith shop by blowers of various kinds. For many years the ordinary bellows was used. This has been superseded by the fan blower which is now almost universally used, even for hand power.

Such a fan blower is shown in Fig. 3. It is formed of a thin cast-iron shell in which there are a set of rapidly revolving blades.

These blades set up a current of air which presses against the side of the shell and escapes through the tangential opening. The pressure of the blast used for an open blacksmith fire varies from about 2 to 7 ounces per square inch. The lower pressure is used for a light fire and light work. The higher pressure is suitable for heavy classes of work.

Fuel. The common fuel for small fires is soft or bituminous coal, coke for large fires and furnaces, and occasionally hard coal in small furnaces. The soft coal used is of a grade known as *smithing coal.* It should be very clean and free from impurities. A lump of good forge coal breaks easily with a crumbly looking fracture and the coal shows clean and bright on all faces. It will not break up into layers as "steaming" coal will, such seamy looking breaks being caused by the more or less earthy impurities. If forge coal splits and shows dull looking streaks or layers, it is poor coal. Good coal has little clinker and breaks easily. When used, the coal is dampened and kept wet before putting on the fire. It should be broken up fine before dampening, and not used in lumps.

Fires. The fire must be carefully watched. It is very important that it should be in first-class condition at all times for the work in hand. A certain depth of fire is always necessary. If the fire be too shallow, the cold blast will penetrate the fire in spots, making it impossible to heat the metal. There should be depth enough to the fire to prevent this. For small work there should be at least three or four inches of fire below the metal that is heating. There should also be thickness enough of fire above the work being heated to prevent the metal from losing heat to the outside air. The fire should be kept as small as possible to heat the work properly. As a general rule the fire will follow the blast. If the fire is wanted larger, it may be made so by loosening the edges of the fire by a bar, allowing the blast to come through around the sides, and causing the fire to spread. When a small fire is wanted the damp coal should be packed down tightly around the sides and the center of the fire loosened up slightly. For light work a small round fire is used. For heavier heating the fire is started by placing a large block on top of the tuyere, on each side of which green coal is packed down hard in the shape of an oblong mound. The block is then removed and the fire started in the hole left. These mounds are left undisturbed and fresh fuel is

added to the fire in the shape of coke which has either been previously made by loosely banking a quantity of green coal over the fire and partially burning it to coke, or is bought ready made. With a small fire the fuel is constantly added around the sides where it is turned into coke. This coke is raked into the center of the fire as wanted and more coal added around the sides and patted down to keep the fire in shape.

When too much blast is blown through the fire all the oxygen is not burned out of the air. This attacks the iron, forming a heavy

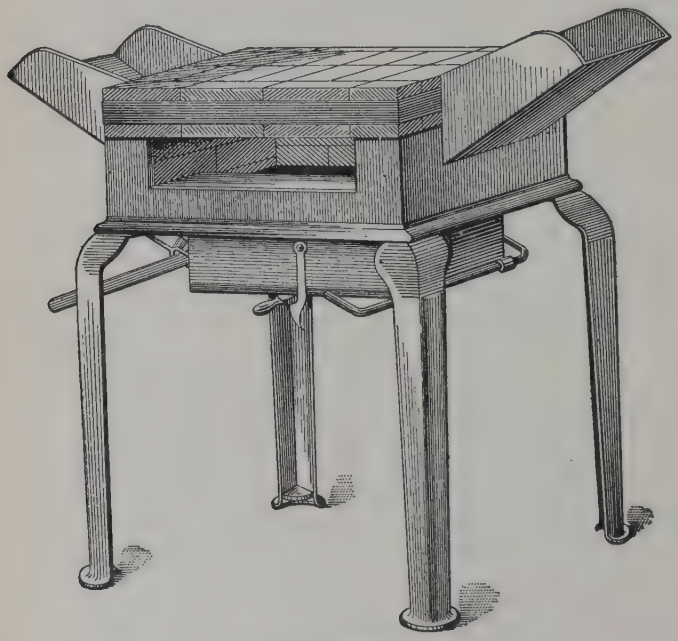


Fig. 4. Small Heating Furnace

coat of oxide or scale (the black scale which falls from heated iron). This sort of fire is known as an *oxidizing fire* and should not be used when it is possible to avoid it. When just enough air is being admitted to keep the fire burning brightly and all of the oxygen is burned, the fire is in good condition for heating. Very little scale is formed and some of the scale already formed may even be turned back to iron. This sort of a fire is known as a *reducing fire*. In other words, when the fire is in condition to give oxygen to anything, it is an oxidizing fire. If in condition to take away oxygen, it is a reducing fire.

Banking. The fire may be kept for some time by placing a block of wood in the center and covering over with fresh coal.

Furnaces. In nearly all manufacturing work and in large work in the jobbing shop, the heating is done in furnaces. The heat is generally supplied by either hard coal, coke, oil, or gas—coke being more commonly employed in jobbing shops. Sometimes ordinary coal is used.

Small Type. A furnace used for heating small work for manufacturing is shown in Fig. 4. This may be used with either ordinary coal or coke. Gas furnaces, a simple type of which for all around work is shown in Fig. 5, are used when an even heat is wanted, particularly for hardening and tempering. For manufacturing work the furnaces are sometimes fixed to do the heating automatically. The pieces to be hardened are carried through the furnace on an endless chain which moves at a speed so timed that the pieces have just time enough to be heated to the right temperature as they pass through the furnace. Such a furnace is shown in Fig. 6.

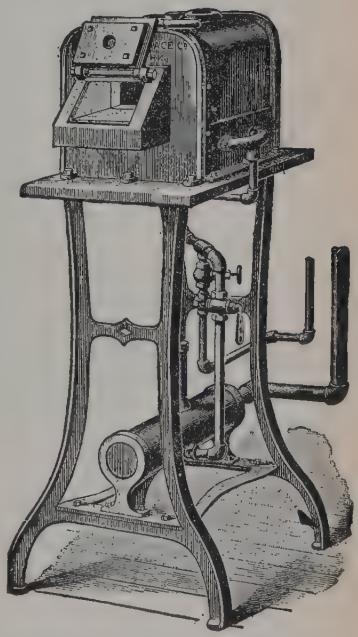


Fig. 5. Simple Gas Furnace
Courtesy of American Gas Furnace Company, New York City

Reverberatory. A reverberatory, or air furnace, is a furnace in which ore, metal, or other material is exposed to the action of flame, but not to the contact of burning fuel. The flame passes over a bridge and then downward upon the material spread upon the hearth. Such furnaces are extensively used in shops where heavy work is being executed. They are also used for melting iron or other metals. For this purpose, however, they are not economical, since they require about twice as much fuel as that used in the cupola for the production of good hot iron. To be effective the flame must be made to reverberate from the low roof of the furnace down upon the hearth and work. The form of the roof and the velocity of the currents determine the hottest part of the furnace.

A common form of reverberatory furnace is shown in Fig. 7. The whole is lined with fire brick from the top of the grates to the

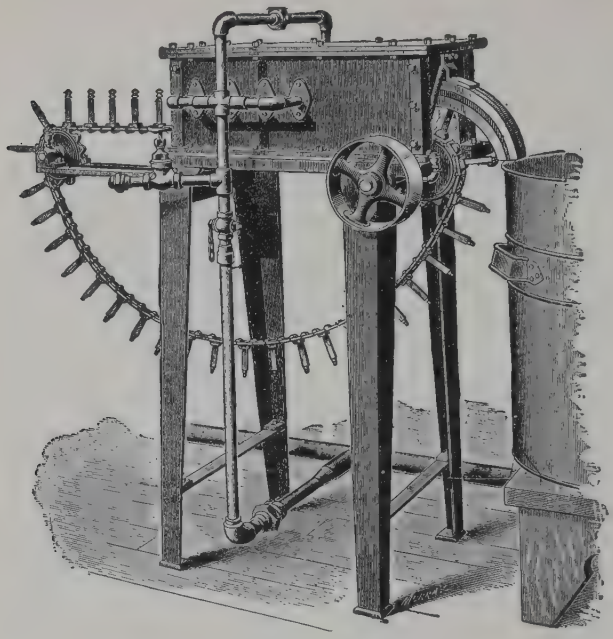


Fig. 6. Automatic Gas Furnace
Courtesy of American Gas Furnace Company, New York City

top of the stack. The fuel is burned in a fire box separated from the heating portion of the furnace by a low bridge wall *D*. Access to

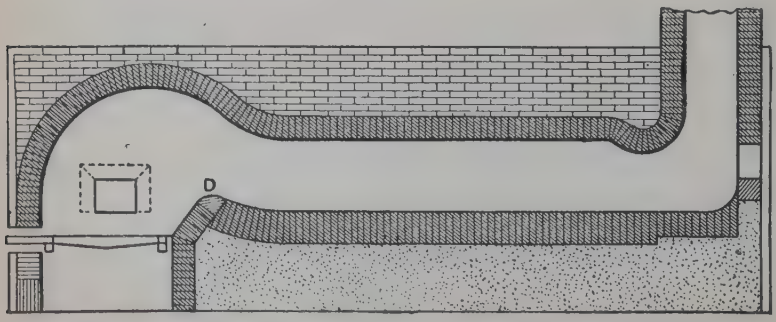


Fig. 7. Section of Reverberatory Furnace

the grate is obtained by suitable doors both above and below. When in service, both doors are tightly closed and a strong forced draft

is admitted to the ash pit. Beyond the bridge wall is the furnace proper. This usually consists of a low chamber with a level floor. Like the fire box it is completely lined with a thick wall of fire brick. Access is obtained to this chamber through a vertically sliding door. These doors are also lined with fire brick and are usually suspended from chains. These pass over pulleys, and have counterbalancing weights at the other end.

The operation of the furnace is exceedingly simple. After the fuel has been charged upon the grates, the ash-pit and furnace doors are closed; the material to be heated is put upon the floor of the chamber; the doors are closed and the draft admitted to the ash pit. The thick walls which surround the furnace prevent radiation of its heat. The fire brick are, therefore, heated to incandescence and the hot gases sweep through the chamber. The flow of the gases is usually checked by a choke damper on top of the stack.

The outer form of these furnaces is usually rectangular. The brick walls are tied together by stay rods to prevent bulging, and the corners are protected by angle irons.

The selection of the fuel is an important matter in the operation of these furnaces. Experiments have been made with almost every kind of fuel. That now universally used is a soft bituminous coal that will not cake.

Steam or power hammers are always used in connection with these furnaces. The work is too large and heavy for manipulation by hand hammers.

COMMON TOOLS

Hammers. Several kinds of hammers are used in a forge shop. The commonest shape is the ball peen shown at *A*, Fig. 8. Other kinds are the straight peen and cross peen illustrated at *B* and *C*. A square-faced hammer, sometimes called a *blacksmith's hammer*, shown at *D*, is occasionally used on tool work. Commonly a ball peen hammer of about $1\frac{1}{2}$ pounds weight is used.

In the fitting of the handle to the head great care should be taken. Hammer handles are made elliptical in cross-section. The major axis of this ellipse should exactly coincide with that of the eye of the head. The reason is that the hand naturally grasps the handle so that its major axis lies in the direction of the line of motion.

Hence, unless the handle is properly fitted in this particular, there will be constant danger of striking a glancing blow. The handle should also stand at right angles to a center line drawn from the ball of the peen to the face. The eye in the head is usually so set that the weight on the face side is greater than that on the peen. The effect

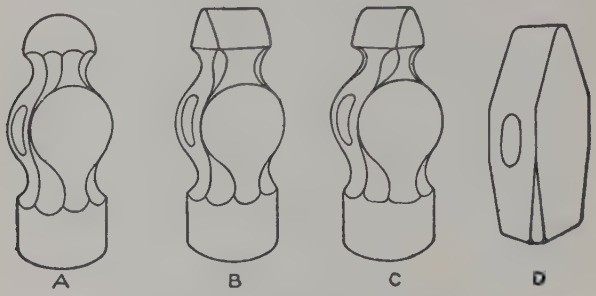


Fig. 8. Common Types of Hammers

of this is to so balance the tool that heavier and more accurate blows can be struck than if the weight were evenly balanced on each side of the eye.

Sledges. Sledges are heavier hammers used by the blacksmith's helper and vary in weight from 5 to 20 pounds. The three common shapes are shown in Fig. 9; *A*, *B*, and *C*, being cross-peen, straight-peen, and double-faced sledges, respectively. A sledge for common

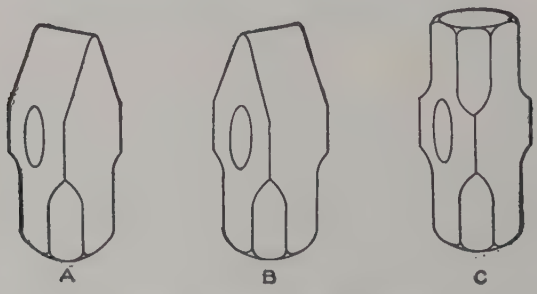


Fig. 9. Common Types of Sledges

work ordinarily weighs about 12 pounds. Sledge handles are generally about 30 to 36 inches long, depending on the nature of the work to be done.

Anvils. Next to the hammer in importance is the anvil. This may be any block of metal upon which the piece to be shaped is laid.

The anvil must be of such a weight that it can absorb the blows that are struck upon it without experiencing any perceptible motion in itself.

The ordinary anvil, Fig. 10, has remained unchanged in form for many hundreds of years. Anvils are sometimes made of special shapes, but the one here shown is the common one. An anvil of this form serves for the execution of any work that may be desired. As now made, the body *a* is of wrought iron to which a face of hardened steel is welded. From one end there projects the horn *b*, and the overhang of the body at the other end *c* is called the tail. At the bottom there are four projections *d*, called the feet, which serve to increase the base upon which the anvil rests as well as to afford the means for clamping it down into position. In the tail there is

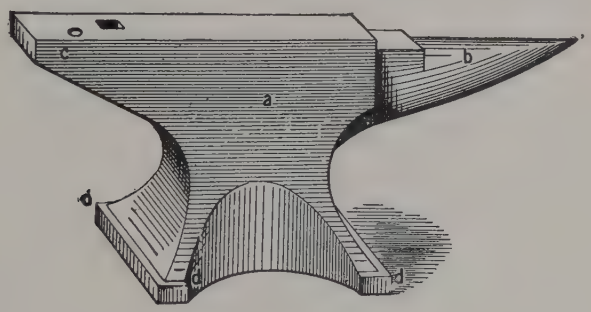


Fig. 10. Anvil

a square hole and a circular hole. The former is called the *hardie hole*, the latter the *spud hole*.

Anvils are also made of cast iron with the working faces chilled, thus giving a sort of casehardening effect.

The anvil should be placed upon the end of a heavy block of wood sunk into the ground to a depth of at least 2 feet, so that it may rest upon a firm but elastic foundation. As the anvil is subjected to constant vibrations, by the nature of the work, it is necessary that it should be firmly fastened to the block.

Weight Classification. Anvils are classed and sold by weight. The weight is generally stamped on the side of the anvil. Three numbers are used. The first to the left shows the weight in English hundredweight of 112 pounds each. The middle number shows the additional quarters of hundredweight and the right-hand figure the number of odd pounds. For instance, an anvil marked 2-3-4 would

weigh $2\times112+\frac{3}{4}$ of 112+4 pounds=312 pounds and would be known as about a 300-pound anvil.

Tongs. Next to the hammer and anvil in importance and usage are the tongs. They vary in size from those suitable for holding the smallest wires to those capable of handling ingots and bars of many tons in weight. The jaws are also adapted to fit over the piece to be handled and are of a great variety of shapes. As the requirements of each piece of work vary so much from those which precede and follow it, it is customary for the blacksmith to dress his own tongs and adapt them, from time to time, to the work he has in hand. Comparatively few, therefore, of the various shapes of tongs found in shops are manufactured and for sale. A few of the general types and forms in common use are here given.

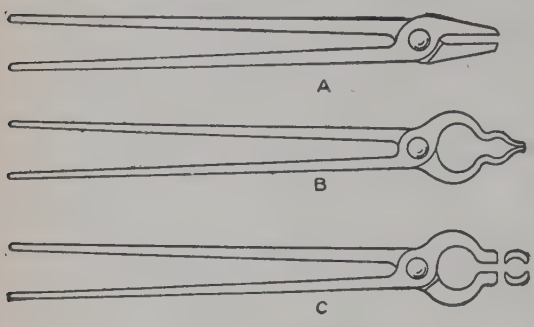


Fig. 11. Types of Tongs

A, Fig. 11, shows a pair of flat-jawed tongs, the commonest shape used. *B* is a pair of pick-up tongs used for holding work while tempering, and picking up pieces of hot metal. *C* is a common shape used for holding both square and round iron, the jaws being bent to fit the stock in each case. A modification of this shape is also used for heavy steam-hammer work. Tongs frequently have the jaws made in some special shape for a particular piece of work, the object always being to have the jaws grip the work as firmly as possible.

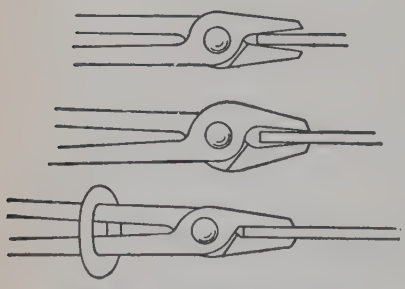


Fig. 12. Fitting Tongs for Work

Fitting Tongs to Work. Tongs must be always carefully fitted to the work. Tongs which take hold of the work as shown at *A* and *B*, Fig. 12, should not be used. The first pair shown have the jaws too

close together, the second, too far apart. When properly fitted the jaws should touch the work throughout the entire length as shown in the lower sketch *C*. To fit tongs the jaws are heated red hot, the piece to be held placed between them, and the jaws hammered down until touching their entire length. Tongs which do not fit the work perfectly should never, under any circumstances, be used. When in use on all but the smallest work, a link is driven over the handles to grip the tongs in position, as shown.

Set Hammers and Flatters. These tools are used for smoothing off flat work when finishing. The set hammer, Fig. 13, is used for work-

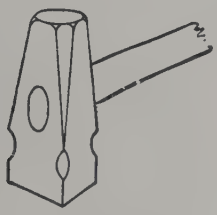


Fig. 13. Set Hammer

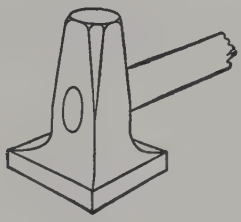


Fig. 14. Flatter

ing up into corners and narrow places. The flatter, Fig. 14, is used on wide flat surfaces. The face of the set hammer used on light work is generally about $1\frac{1}{4}$ inches square. That of the flatter about $2\frac{1}{2}$ inches square, although the sizes vary, depending upon the kind of work.

Swages. Swages, shown in Fig. 15, are used for finishing round and convex surfaces. The upper tool is known as the top swage and is provided with a handle. The lower one is the bottom swage and is held in place by a square stem or shank which extends downward and fits into the hardie hole of the anvil. Tools of this character should never be used on an anvil where they fit so tight that it is necessary to drive them into place. The swages shown here are used for round work. Swages are also made for octagonal, hexagonal, and other shapes.

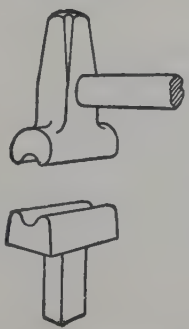


Fig. 15. Swages for Round Work

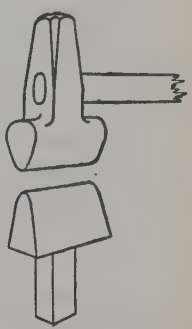


Fig. 16. Fullers

Fullers. Fullers, which are used for working grooves or hollows into shape, are also made top and bottom as shown in Fig. 16. The top fuller is for finishing into round corners, around bosses, and on the inside of angles as illustrated later on. The fuller is also used to spread metal when it is wished to work the metal only in one direction. The metal spreads at right angles to the working edge of the fuller.

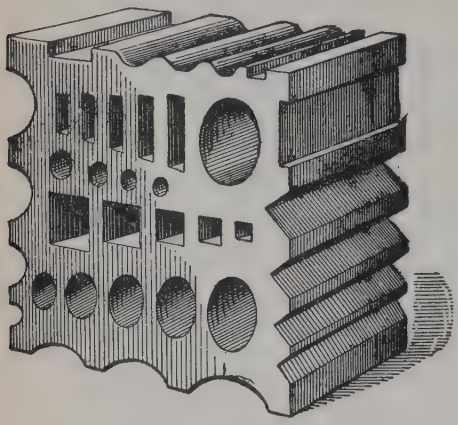


Fig. 17. Swage Block

Swage Blocks. Swage blocks, a common sort of which is shown in Fig. 17, are used for a variety of purposes, mostly for taking the place of bottom swages. These blocks are commonly made from cast iron and weigh about 150 pounds.

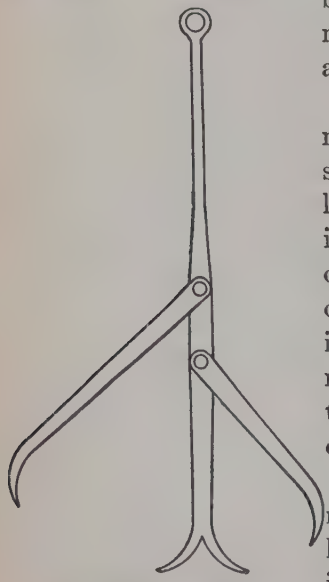


Fig. 18. Double Calipers

Other Tools. The tools used commonly are calipers, a carpenter's 2-foot steel square, dividers, rule, shovel, tongs, ladle, poker, and a straight bar for loosening the fire. In addition to the ordinary calipers, a blacksmith usually has a pair of double calipers similar to those shown in Fig. 18. With these, two dimensions may be used, one side being set for the thickness, and the other for the width, of the material.

Measuring. When several measurements are to be made particularly on large work, a strip of light stock about $\frac{1}{8}$ inch by 1 inch wide is used. The different dimensions are laid off on this with chalk or soapstone. In use the strip is held against the work and used in the same manner as a rule. A light rod having a small

bent end, made by bending over about $\frac{1}{2}$ inch of stock at right angles, is also sometimes used, particularly when working under the steam hammer. The dimensions may be laid off from the inside of the hooked end. When in use the hooked end is pulled against the end of the material. Soapstone crayon is ordinarily used for marking on iron. The marks do not burn off, but will not show at a red heat. Marks to show at a high heat must be made by nicking the corner of the bar with a chisel or by marking with the center punch. Another common way of making measurements on hot material is to lay off the different distances on the side of the anvil with chalk, the dimensions being laid off from one corner or end.

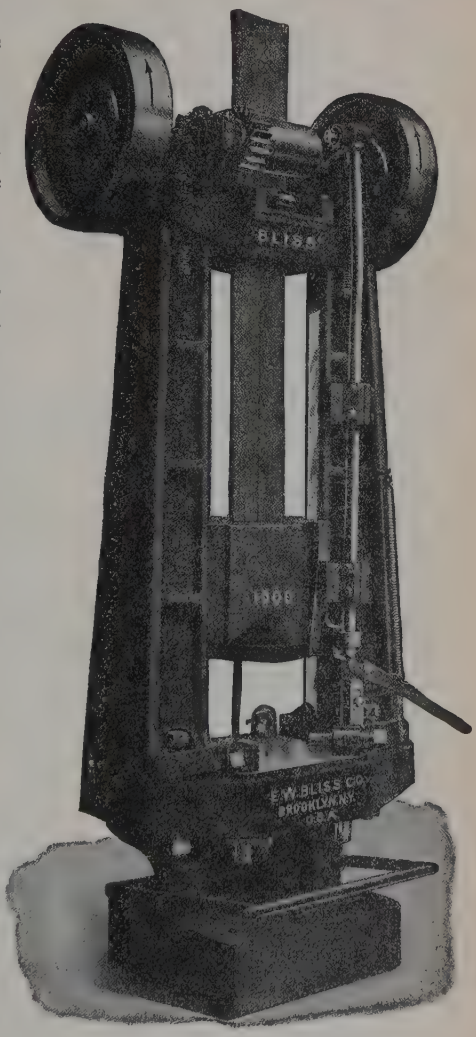


Fig. 19. Board Drop Hammer
Courtesy of E. W. Bliss Company, Brooklyn, New York

MACHINE TOOLS

Manufacturing Requirement. The manufacturing shop differs very essentially from the jobbing shop. In the latter shop very few forgings are made at the same time exactly alike, while in manufacturing, each forging is generally duplicated a large number of times and special machines are used for doing the work.

Drop Hammers. Drop hammers are used for quickly forming complicated shapes out of wrought iron or steel. They consist,

as the name indicates, of a head that may be "dropped" from any desired height upon the piece to be shaped. The head of the drop and the anvil are in the form of dies into which the metal is forced to flow, and thus take on the form desired. In drop-forging, the metal must be heated to a high temperature so as to be soft and plastic.

A common type of drop hammer used for this kind of work is shown in Fig. 19. The hammer in this case is fastened to a board and is raised by the friction rollers at the top of the frame being pressed against the board. When the hammer reaches the top of the frame it is dropped by releasing the rollers from the board. This may be done automatically or by a foot treadle. Drop hammers are also built in the same general way as steam hammers, as referred to in the sections on Heavy Forging and Drop Forging. Dies for drop forging generally consist of a roughing or breaking-down die where the rough stock is first given approximately the desired shape and a smoothing die when the finishing is done. These dies have in their faces holes of the same shape as the required forging.

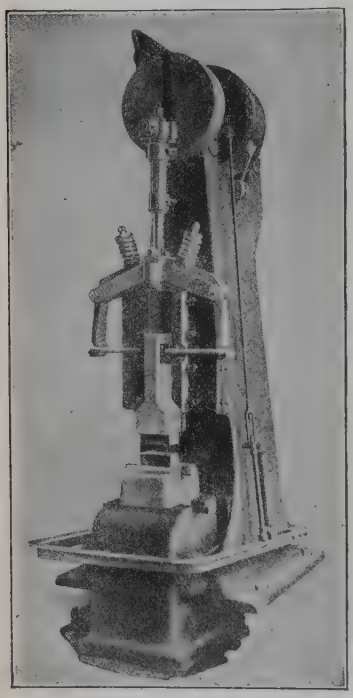


Fig. 20. Justice Hammer

Power Hammers. Another tool which is used to quite a large extent in manufacturing, as well as in the jobbing shop, is the power hammer. These are run by belts and are used where a quick rapid blow is wanted. The type shown in Fig. 20 is known as a Justice hammer; that shown in Fig. 21 is a Bradley. Shaped dies are frequently used on these hammers.

Spring-Ram Type. Fig. 22 shows the Beaudry power hammer. This hammer has many claims in its favor—superior elasticity; perfect control of blow struck. These are obtained by a device which is simple and effective, allowing the ram the greatest freedom of throw and causing it to rebound the instant the blow is struck.

This hammer has no beam, saddle, rubber cushions, leather straps, nor coiled springs. Its ram or head is of steel and has an internal curve or track of () shape, as shown by the sectional cut, Fig. 23. Two steel spring arms with hardened tool-steel rollers at their lower extremities operate within the ram which, with increased speed of hammer, acquires increased travel and force of blow.

This simple and positive action of the spring arms perfectly controls the ram and causes it to rebound the instant the blow is

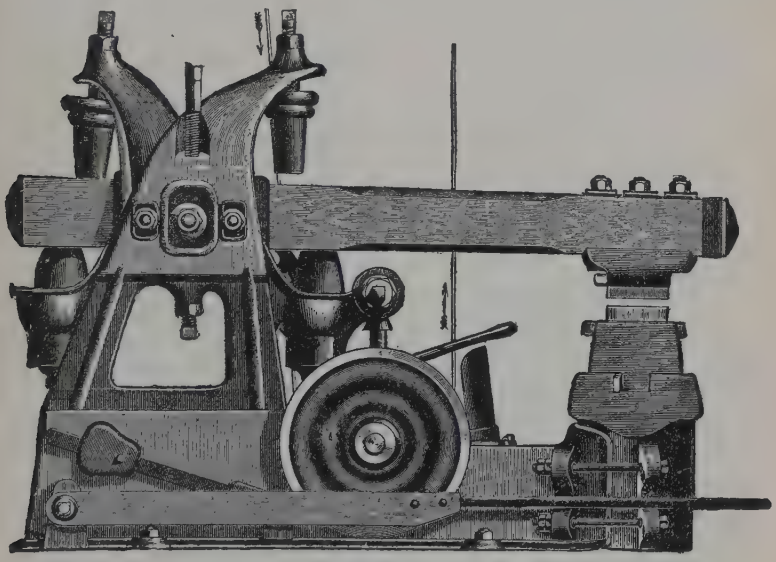


Fig. 21. Bradley Power Hammer

struck, without reaction or jump or sudden undue strains on any of the hammer parts. The elasticity and force of the blow is obtained thus, and by it the full stroke can be had as readily on a piece 4 inches square as on a piece $\frac{1}{8}$ inch in thickness, and no change of adjustment is necessary excepting for unusually heavy work.

The hammer is started, stopped, and regulated by a foot treadle which extends around the base of the machine and through a varying pressure on which there is obtained instantly any desired speed or force of blow of from 1 pound up to its full capacity, which latter is an estimated maximum blow of six times the weight of the ram.

The anvil clears the main frame casting as shown in Fig. 24, allowing any length bars to be worked either way of dies. It is an inde-

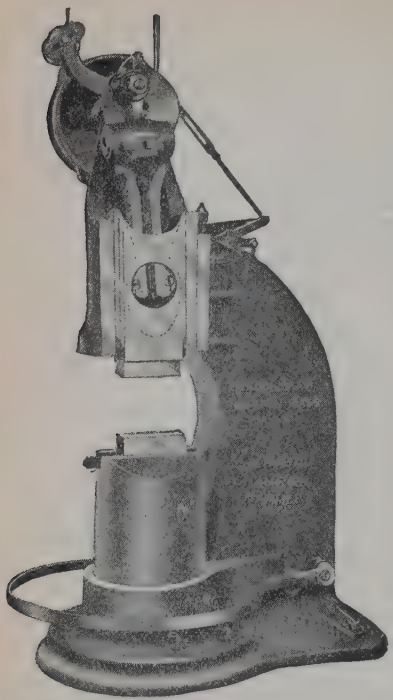


Fig. 22. Beaudry Spring-Ram Power Hammer
Courtesy of Beaudry & Company, Boston, Massachusetts

pendent casting having no connection with the frame, and thus preventing crystallization of the hammer parts; it is held in place by its own foundation bolts and stands in the center of the hammer foundation. To it is keyed an independent show die and to that in turn is keyed the bottom die.

Presses. Presses may be of either the gear-driven or the hydraulically operated type. They serve the same purpose as drop hammers. They do the work more slowly, however. The class of work is, in some respects, the same, the principal difference lying in peculiarities of shape that require different time intervals for the flow of the metal. Where the shape is such that the

Fig. 23. Close View of Beaudry Ram

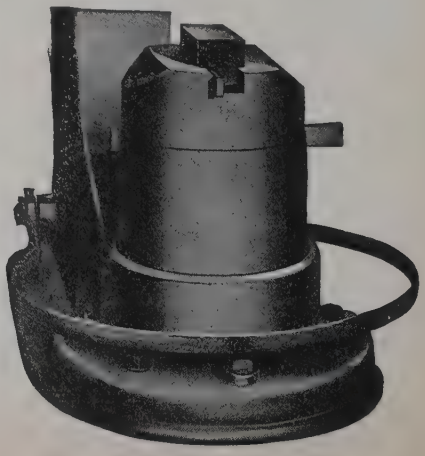


Fig. 24. Close View of Beaudry Anvil

metal must move slowly in order to acquire its new shape or fill the die, the press should be used.

Flanging Type. A particular type of forging press is the flanging press. This is used more particularly in boiler work and is generally a heavy hydraulic press. The flanging is done by placing the heated metal on the bed of the press and closing the dies together by hydraulic pressure.

Bulldozer. This is a tool used for bending and consists of a heavy cast-iron bed with a block or bolster at one end, and a moving head which slides back and forth on the bed. A common type is shown in Fig. 25. Heavy dies are clamped against the bolster and

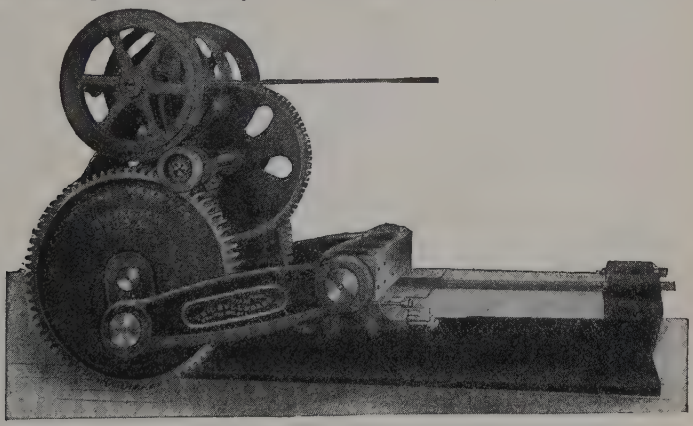


Fig. 25. Bulldozer—Used for Bending Stock
Courtesy of Williams, White & Company, Moline, Illinois

on the moving head, of such a shape and in such a way that when the moving head is nearest the bolster, the shape left between the two dies is exactly the shape to which it is desired to bend the stock. In operation, the moving head slides back and forth on the bed. The bar to be bent is heated and placed between the dies when the head is farthest from the bolster. A clutch is then thrown in and the head moves forward to the bolster, bending the iron as it goes.

Bolt Headers. These are really upsetting machines that form the heads of bolts upon straight rods. Owing to the rapidity with which they do their work, they are invariably used for manufacturing bolts in quantities.

Cranes. Where heavy work is to be handled, it is necessary to have some means of conveying the work from one part of the shop to

another. This is done by means of cranes of two general types: (1) the traveling crane; and (2) the jib crane. The former type runs on an overhead track from one end of the shop to the other, generally.

Jib Type. The jib crane type is used more commonly for handling work under the hammers, and is merely an arm or boom swinging around a post and having a suitable arrangement for raising and lowering the work. When handling heavy work, whenever possible, it is suspended from the crane by its center, in such a way that it nearly balances. The suspending is generally done by means of an endless chain such as illustrated in Fig. 26, and in this way it may be easily rolled and swung from side to side. For ease in handling large forgings, a bar or handle known as a *porter bar* is sometimes welded on.

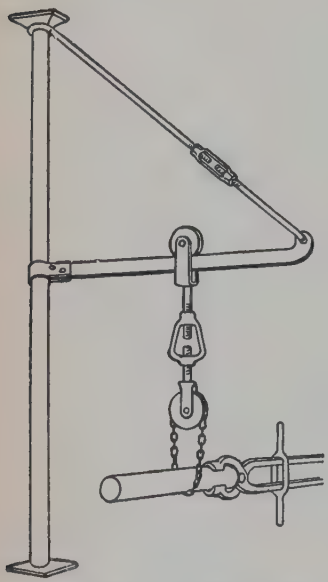


Fig. 26. Work Supported by Jib Crane

FORGING OPERATIONS

SMITH WELDING

Nature of Process. If a piece of steel or iron is heated, the metal becomes softer as the temperature is raised. Finally a heat is reached, called the welding heat, at which the metal is so soft that, if two pieces similarly heated are placed in contact, they will stick. If the pieces so heated are placed together and hammered, they may be joined in one piece. This process is known as *welding.*

Welding Heat. The greatest difficulty in welding is to heat properly, which must be done evenly and cleanly. If the temperature is raised too high, the iron will burn, throwing off bright star-like sparks. If the temperature is too low, the pieces will not stick to each other. The proper heat can only be determined by experimenting, which may be easily done by doubling over a piece of scrap iron for 2 or 3 inches and welding into a solid piece.

As the welding heat is reached, in heating wrought iron and mild steel, small particles of the metal are melted and blown upward from the fire by the blast, and as these small particles come in contact with the air, they burn and form small explosive sparks like little white stars. Whenever these sparks are seen coming from the fire, it is a sure indication that the iron is burning. They are sometimes used as a sort of an indication of the welding heat, but the only sure way of determining the heat is by the appearance of the heated iron, which might be described as sort of creamy white. The welding heat is sometimes described as a white heat. This is not correct, because iron or steel is never raised to a white heat even when melted, as may be easily proved by comparing a piece of wrought iron at welding heat, with an ordinary arc lamp.

Scale. When two pieces of metal are welded together there must be nothing between them. Heated iron or steel is always covered with scale (iron oxide). This scale, if allowed to stay on the surfaces to be joined, will prevent a good weld. It is necessary when welding, to heat the iron or steel to a high enough temperature to melt this scale and when the two pieces are put together, if the joint or scarf is properly made, most of this melted scale is easily forced from between the two pieces, leaving the clean surfaces of the metal in contact. This scale only melts at a very high heat, much higher than the heat at which it would be possible to weld the iron if it could be kept free from scale.

Fluxes. Fluxes are used to lower the melting point of the scale. The flux is sprinkled on the surfaces to be joined just before the metal reaches the welding heat. The metal is then put back into the fire, raised to the welding heat and the weld made as usual. The scale is acted upon by the flux and melts at a lower heat than when no flux is used. As the flux melts it spreads or runs over the hot metal and forms a sort of protective covering, which, by keeping out the air, prevents to a large extent the formation of more scale. The flux in no way acts as a cement or glue to stick the pieces together, but merely helps to melt off the scale already formed, and prevents the formation of more.

Sand and Borax. These substances are common fluxes. Sand may be used when welding wrought iron and machine steel; borax is substituted for sand for fine work and when welding tool steel.

Borax is a better flux, as it melts at a lower temperature than sand, and thus makes welding possible at a lower heat. Borax and sal ammoniac (ammonium-chloride) are sometimes mixed and used as a welding compound or flux, the proportion being about 4 parts borax to 1 part sal ammoniac. This mixture is also a good flux for brazing. Borax contains a large amount of water which makes it boil and foam when melting and in this condition is very liable to drop away from the heating metal. If borax is heated red hot and allowed to cool, the water is driven off and the borax is left in a glass-like condition. Borax treated this way and then powdered is the best for welding, as it melts and sticks to the metal without any boiling.

Welding Compounds. These are fluxes serving the same purpose as sand or borax. Some of the better ones use borax as a basis. Some of these compounds are first class for their purpose and others are not so good, being simply intended as cheap substitutes for borax.

Processes

Scarfing. For most welding the ends of the pieces to be joined must be so shaped that when welded they make a smooth joint. This shaping of the ends is known as scarfing, and the shaped end is called a scarf. The scarfed ends should not fit tightly before welding but should be so shaped that they touch in the center of the joint, leaving the sides somewhat open. In this way, when the weld is made, the melted scale is forced from between the pieces. If the scarfs were made to touch on the edge of the joint, leaving the center hollow, the scale not having a chance to escape would be held in the center of the joint, leaving a weak place, and making a bad weld.

Fig. 27. Work Scarfed for Lap Weld

Lap Welding. This is the common weld used for joining flat bars together. The ends to be welded are scarfed or shaped as

shown in Fig. 27. In preparing, the ends of the pieces to be welded should be first upset until they are considerably thicker than the rest of the bar. This is done to allow for the iron that burns off or is lost by scaling, and also to allow for the hammering when welding the pieces together. To make a proper weld the joint should be well hammered, and as this reduces the size of the iron at that point, the pieces must be upset to allow for this reduction in size. For light

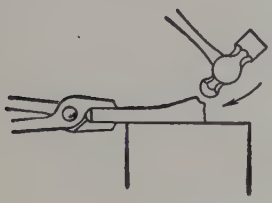


Fig. 28. Shaping Scarf

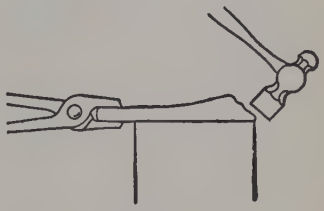


Fig. 29. Finishing Scarf

work the scarfing may be done with a hand hammer. For heavy work a fuller and sledge should be used. After upsetting on light work, the end to be scarfed is roughly shaped with the peen end of the hammer as illustrated in Fig. 28, the final finishing being done with the flat face of the hammer.

For this work (finishing the edge of the scarf) as well as for all pointed work, the end of the bar should be brought to the extreme edge of the anvil in the manner indicated in Fig. 29. In this way a hard blow may be struck with the center of the face of the hammer without danger of striking the hammer on the anvil. For all ordinary lap welding the length of the scarf may be about $1\frac{1}{2}$ times the thickness of the bar. Thus, on a bar $\frac{1}{2}$ inch thick, the scarf will be about $\frac{3}{4}$ of an inch long. The width of the end, Fig. 27, should be slightly less than the width of the bar. In welding the pieces together the first piece held by the helper should be placed scarf side up on the anvil and the second piece laid on top, scarf side down, overlapping them to about the amount shown in Fig. 30. As it is generally somewhat difficult to lay the top piece directly in

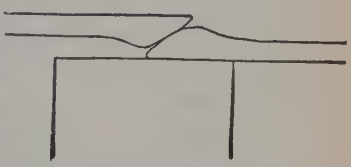


Fig. 30. Overlapping for Weld

place, it should be steadied by resting lightly against the corner of the anvil and thus guided into place.

Round Lap Weld. This is the weld used to join round bars end to end to form a continuous bar. All the precautions regarding the scarf, etc., used for making the lap weld should be taken with this as well. The general shape of the scarf is shown in Fig. 27. It will be noticed that the end is hammered to a sharp point. If the scarf be made with a flat or chisel-shaped end similar to the flat lap weld, the corners will project beyond the sides of the bar in welding and cause considerable trouble, as it will then be necessary to work entirely around the bar before the joint is closed down. With a pointed scarf the weld may be frequently made by hammering on two sides only. This is not so important when welding between swages.

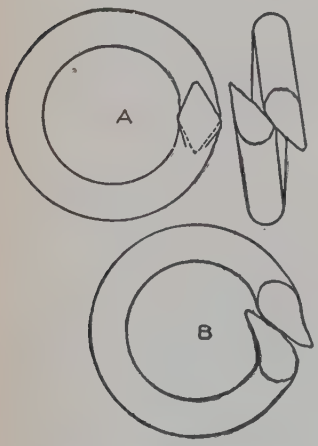


Fig. 31. Lapping Ring Ends

Ring Round Stock. When a ring is made, the exact amount of stock may be cut, the ends upset and scarfed as though making a round lap weld, the stock bent into shape, as shown in Fig. 31, and welded. The ends should be lapped sideways as shown at *A*. In this position a ring may be welded by simply laying it flat on the anvil, while if lapped the other way, *B*, one end in, the other out, it would be necessary to do the welding over the horn of the anvil. In all welding the piece should be so lapped that the hammering may be done in the quickest and easiest manner.

Allowance for Welding. In work of this character, when the stock is cut to a certain length, allowance is sometimes made for loss due to welding. The exact amount is hard to determine, depending on how carefully the iron is heated and the number of heats required to make the weld. The only real loss which occurs in welding is the amount which is burned off and lost in scale. Of course, when preparing for the weld, the ends of the pieces are upset and the stock consequently shortened. The piece is still further shortened by overlapping the ends when making the weld, but as all of this material

is afterward hammered back into shape, no loss occurs. No rules can be given for the loss in welding, but as a rough guide on small work, a length of stock equal to from $\frac{1}{4}$ to $\frac{3}{4}$ of the thickness of the bar will probably be about right for waste. Work of this kind should be watched very closely and the stock measured before and after welding in order to determine exactly how much stock is lost.

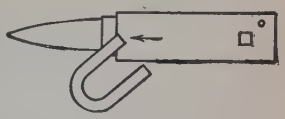


Fig. 32. Scarfing Chain Link

Chain Links. The first step in making a chain link is to bend the stock into a U-shape, care being taken to have the legs of the U exactly even in length. The scarf used is approximately the pointed shape used for a round lap-weld scarf. An easy method is as follows: One end of the U-shaped piece is laid on the anvil as indicated in Fig. 32. This is flattened by striking directly down with the flat face of the hammer, the piece being moved slightly to the left, as shown by the arrow, after each blow, until the end is reached.

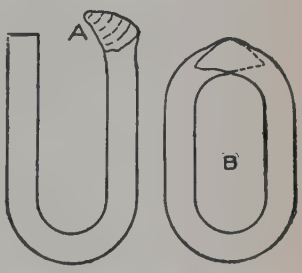


Fig. 33. Shaping and Finishing Scarf

This operation leaves a series of little steps at the end of the piece and works it out in a more or less pointed shape, as shown in Fig. 33 at *A*. The point should be finished by placing it over the horn of the anvil and touching up with a few light blows. After scarfing the other end of the U in the same manner the, ends are overlapped as indicated at *B* and welded together. The second link is scarfed, spread open, and the first link inserted. It is then closed up again and welded. The third is joined on this, etc. When made on a commercial scale, light links are not always scarfed but sometimes simply hammered together and welded in one heat. This is not possible in ordinary work.

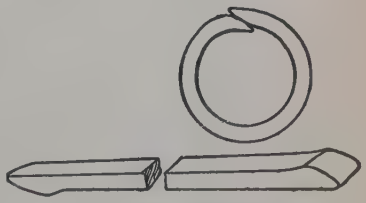


Fig. 34. Band Ring

Band Ring. A method of making a band ring from iron bent flatways is illustrated in Fig. 34. Stock is cut to length, the ends upset and scarfed, using a regular flat-weld scarf, and the ring bent

into shape and welded; the welding being done over the horn of the anvil. The heating must be carefully done or the outside lap will be burned before the inside is nearly hot enough to weld.

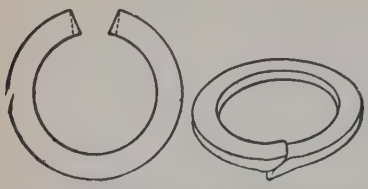


Fig Shaping Flat Ring

Fig. 36. Flat Ring Ready for Welding

Flat or Washer Ring. This is a ring made by bending flat iron edgeways. The ends of the stock are first upset but not scarfed, except for careful work, the ring bent into shape, and the corners trimmed off on radial lines as shown in Fig. 35. The ends are then scarfed with a fuller or peen of a hammer and lapped over ready for welding as shown in Fig. 36.

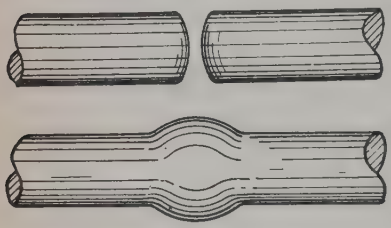


Fig. 37. Typical Butt Weld Before and After Welding

Butt Welding. When pieces are simply welded together end to end, making a square joint through the weld, it is known as a butt weld. It is best when making a weld of this kind to round the ends slightly, as illustrated in Fig. 37. The ends are heated and driven together and this round shape forces out the scale and leaves a clean joint. As the pieces are driven together they are more or less upset at the joint, making a sort of a burr. This upset part should be worked down at a welding heat between swages. A butt weld is not as safe or as strong as a lap weld. Long pieces may be butt-welded by placing one piece in the fire from each side. When the welding heat is reached the pieces are placed end to end, one piece "backed up" with a heavy weight, and the weld made by striking with a sledge hammer.

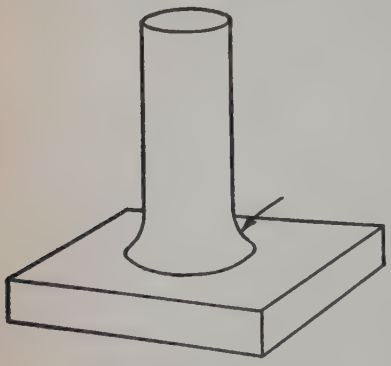


Fig. 38. Jump Weld

Jump Weld. Another form of butt weld shown in Fig. 38 is a jump weld which, however, is a form that should be avoided as

much as possible, as it is very liable to be weak. In making a weld of this kind, the piece to be butted on the other should have its end upset in such a manner as to flare out and form sort of a flange, the wider the better. When the weld is made, this flange may be worked down with a fuller or set hammer, thus making a fairly strong weld.

Fig. 39. Cleft or Split Weld

Split Welding Heavy Stock. Heavy stock is sometimes welded by using a scarf of the shape shown in Fig. 39. One piece is split and shaped into a Y while the other has its end brought to a blunt point. When properly shaped, the pieces are heated to the welding heat and driven together. The ends of the Y are then closed down over the other piece and the weld completed. A second heat is sometimes taken to do this. This weld is often used when joining tool steel to iron or to machine steel. Sometimes the pieces are placed together before taking the welding heat.

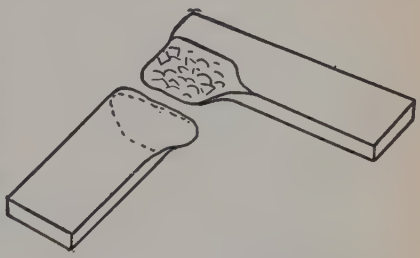


Fig. 40. Right-Angled Weld

Angle Welding. In all welding it should be remembered that the object of the scarfing is to so shape the pieces to be welded that they will form a joint easy to weld and give the proper size for the work. Frequently there are several equally good methods of scarfing for the same sort of a weld, and it should be remembered that the method given here is not necessarily the only way in which that particular weld may be made. Fig. 40 shows one way of scarfing for a right-angled weld made of flat iron. Both pieces are scarfed exactly alike, the scarfing being done by the peen end of the hammer. If necessary, the ends of the pieces may be upset before scarfing. Care should be used to see

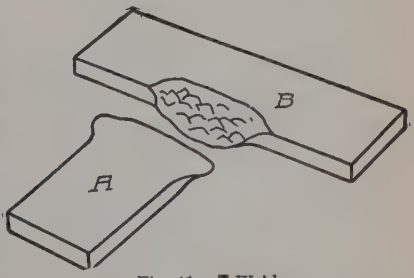


Fig. 41. T-Weld

that the pieces touch first in the center of the scarf, otherwise a pocket will be formed which will retain the scale and spoil the weld.

T-Welding. A method of scarfing for a T-weld is illustrated in Fig. 41. The scarf is formed mostly with the peen end of the hammer; the points are short for easy welding. The stem *A* should be placed on the bar *B*, when welding, so that there is a little lap-over.

Round-Stock T-Weld. Two methods of scarfing for a T-weld made from round stock are shown in Fig. 42. The scarfs are formed mostly with the peen end of the hammer. The illustration will explain itself. The stock should be well upset in either method.

Welding Tool Steel. The general method of scarfing is the same in all welding but greater care must be used in heating when welding tool steel. The flux used for welding tool steel should be the sal ammoniac and borax mixture mentioned before. Spring steel or low-carbon steel may be satisfactorily welded if care is used. To weld steel successfully the following precautions should be observed. Clean the fire of all cinders and ashes. Put sufficient coal upon the fire so that it will be unnecessary to add more coal while taking the welding heat. Upset both pieces near the end and scarf carefully. When possible, punch a hole and rivet the two pieces together. Heat the steel to a full red heat and sprinkle with borax. Replace in the fire and raise to the welding heat. Clean the scarfed surface and strike lightly at first, following with heavier blows. The appearance of steel when at a welding heat is a pale straw color. Always avoid a weld of high-carbon steel alone, when possible.

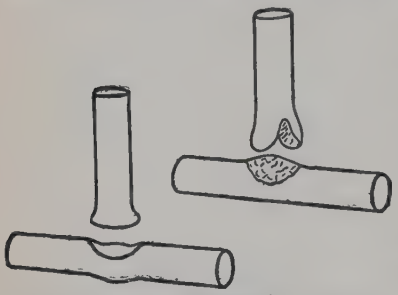


Fig. 42. Method of Making T-Weld for Round Stock

Welding Steel and Wrought Iron. Steel may also be welded to wrought iron. This is done in the manufacturing of edged tools. The body of the tool is of iron, to which a piece of steel is welded to form the cutting edge. This class of work is best done with a fire of anthracite coal, though coke or charcoal may be used. The fire should be burning brightly when the heating is done. Lay the iron and steel on the coal until they are red hot. Then sprinkle the

surfaces of both with the flux and let it vitrify. A convenient method of doing this is to have the powdered flux (borax preferred) in a pepper pot. As soon as the heat has changed the metals to a straw color lay them together and strike. A single blow of a drop hammer, or four or five with a light sledge will do the work. Be sure that these pieces are well covered with a flux before attempting to weld.

SIMPLE BEND FORGING

Fundamental Forging Operations

Shaping. After the metal has been heated it is shaped with the hammer. This shaping may consist of drawing, upsetting, or bending. In drawing a bar of iron it is made longer and of smaller diameter. Upsetting consists of shortening the bar with a corresponding increase of diameter. This work is usually done with the assistance of a helper using a sledge hammer; the smith using a light hand hammer. They strike alternate blows. The helper must watch the point upon which the smith strikes and strike in the same place. Where two helpers are employed the smith strikes after each man. A blow on the anvil by the smith is a signal to stop striking.

Finishing. As the hammer usually marks the metal, it is customary to leave the metal a little full and to finish by the use of flatters and swages. This applies to work that has been shaped under the sledge. Light work can be dressed smoothly, and the hammer can be made to obliterate its own marks.

Drawing Out. In drawing out, as well as in all other forging operations where heavy work is to be done, it is always best to heat the work to as high a temperature as the metal will stand without injury. Work can sometimes be drawn out much faster by working over the horn of the anvil than on the face, the reason being this: When a piece of work is hammered on the anvil face it flattens out and spreads nearly as much in width as it does in length, working it out longer and wider. As the piece is not wanted wider but merely longer, all the work spent in increasing the width of the stock is wasted. If the hammering is done over the horn of the anvil as illustrated in Fig. 43, the rounded

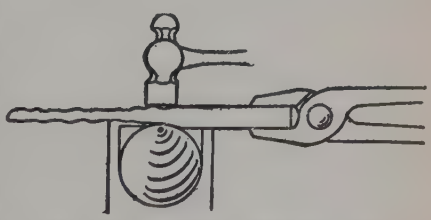


Fig. 43. Method of Drawing Out Work

horn acts as a blunt wedge, forcing the metal lengthwise and thus utilizes almost the entire energy of a blow in stretching the metal in the desired direction. Fullers are also used to serve the same purpose and when working under the steam hammer a round bar sometimes takes the place of the fuller or horn of the anvil.

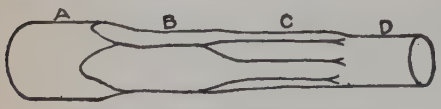


Fig. 44. Drawing Down Round Bar

Round Stock. When drawing out or pointing round stock, it should always first be forged down square to the required size and then rounded up in as few blows as possible. Fig. 44 illustrates, in a general way, the different steps in drawing down a round bar from a large to a smaller size, the first step being to hammer it down square as at *B*. This square shape is then made octagonal as at *C* and the octagon is finally rounded up as at *D*. If an attempt be made to hammer the bar by pounding it round and round without the preliminary squaring, the bar is very liable to split through the center, the action being a good deal as illustrated in Fig. 45, the effect of the blow coming as shown by the arrows *A*. The metal is squeezed together in this direction and forced apart in the direction at right angles as indicated by the arrows *B*. Then, if the piece be slightly rolled for another blow, the sides will roll by each other, and cracks and splits will sooner

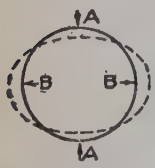


Fig. 45. Wrong Method of Drawing Out

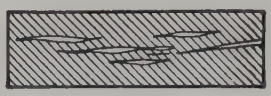


Fig. 46. Section Showing Result of Wrong Drawing

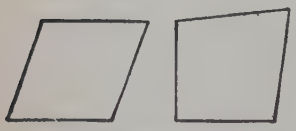


Fig. 47. Irregular Shapes

Fig. 48. Method of Squaring Up Bad Corners

or later develop, leaving the bar, if it should be sawed through the center, in a good deal the shape shown in Fig. 46. Particular care should be taken in making conical points as it is almost impossible to work stock to a round point unless the point be first forged down to a square or pyramidal shape.

Truing Up Work. In drawing out it often happens that the bar becomes worked into an irregular or diamond shape, similar to the section shown in Fig. 47. To remedy this, and square up the bad corners, the bar should be laid across the anvil and worked much as shown in Fig. 48, the blows coming in the direction indicated by the arrow. Just as the hammer strikes the work it should be given a sort of sliding motion. No attempt should be made to square up a corner by striking squarely down upon the work. The hammering should all be done in such a way as to force the metal back into the bar and away from the high corner.

Upsetting. When a piece is worked in such a way that its length is shortened and either or both its thickness and width increased, the piece is said to be upset and the operation is known as *upsetting*. There are several methods of upsetting, the one used depending largely upon the shape of the work. In short pieces the work is generally stood on end on the anvil, the hammering being done directly down upon the upper end. The work should always be kept straight, and as soon as a bend or kink is started, it should be straightened out. When a long piece is to be upset it is generally swung back and forth horizontally and the upsetting done by ramming the end against the anvil. The effect of the blow has a decided influence upon the shape of the upset piece, as shown in Fig. 49. Light blows affect the metal for a short distance only, as shown by the swelled out end; the heavier blows are felt more uniformly throughout the entire length.

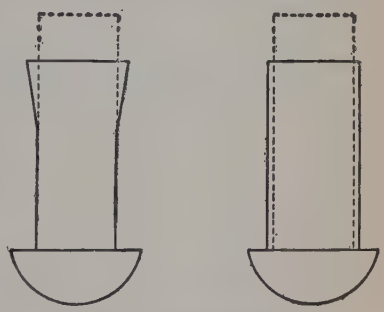


Fig. 49. Upsetting Rivets

When rivets are to be driven to fill holes tightly, the blows should be heavy, thus upsetting the rivet tightly into the holes. If a rivet is wanted to hold two pieces together in such a way that they may move, as for instance the rivet in a pair of tongs, the head should be formed with light blows, thus working only the end of the rivet. The part of the work which is heated to the highest temperature is the part which will be most upset, and when upsetting is wished at one point only, that point should be heated to the

highest temperature, leaving the other parts of the bar as cold as possible. Upsetting long pieces is sometimes done by raising the piece and allowing it to drop on a heavy cast-iron plate set in the floor. These plates are known as upsetting plates.

Fig. 50. Punch for Round Holes

Punching. Two kinds of punches are commonly used for making holes in hot metal; the straight hand punch used with a hand hammer, and the one used for heavier stock, provided with a handle and used with a sledge hammer. Punches should of course be made of tool steel. For punching small holes in thin iron a hand punch is ordinarily used. This is a bar of round or octagonal steel, 8 or 10 inches in length, with the end forged down tapering to the same shape, but slightly smaller than the hole to be punched. Such a punch for round holes is shown in Fig. 50. The end of the punch should be perfectly square across, not at all rounding. For heavier and faster work with a helper, a punch similar to Fig. 51 is used, the striking being done with a sledge hammer.

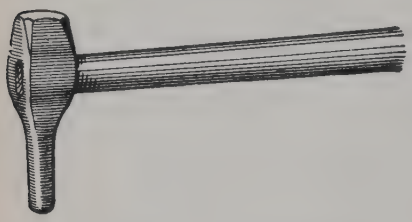


Fig. 51. Punch for Heavy and Fast Work

Correct Hand Method. Fig. 52 illustrates the successive steps in punching a clean hole through a piece of hot iron. The work is first laid flat on the anvil and the punch driven about half way through as shown at *A*. This compresses the metal directly underneath the end of the punch and raises a slight bulge on the opposite side of the bar. The piece is then turned over and the punch driven into the bar from this side (the hole being located by the bulge) while the bar is lying flat on the anvil. The punch should be driven about half way through, leaving the work as at *C*. The bar is then moved over the small round hole in the end of the anvil, or is placed on some object having a hole slightly

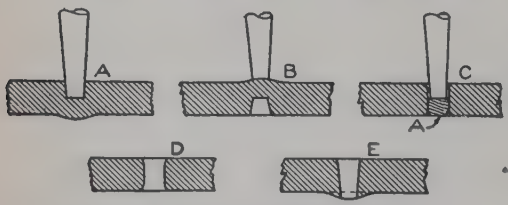


Fig. 52. Stages of Punching Round Hole

larger than the hole to be punched, and the punch is driven clear through, forcing out the small piece *A* and leaving the hole as shown at *D*. It would seem easier to drive the punch completely through the work from one side. If this were done, however, the hole would be left as shown at *E;* one side would be rounded in, and the other side would be bulged out, while the hole would have a decided taper, being larger at the end from which the punching was done. If the piece is thick, a little powdered coal is put in the hole after it is started, to prevent the punch from sticking to some extent.

Calculation of Stock for Bent Shapes

Mathematical Calculation. *Angles.* It is always convenient and frequently necessary to know the exact amount of stock required to make a given piece of work. There are four general methods

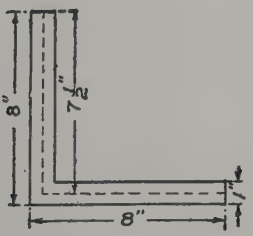


Fig. 53. Diagram for Calculating Stock in Bent Piece

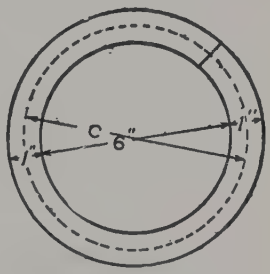


Fig. 54. Diagram for Calculating Stock in Ring

used for determining this. The first and most accurate method, if it can be used conveniently, is mathematical calculation. Taking as an example the bent piece illustrated in Fig. 53. If the outside of this is measured, it would seem as though 16 inches of stock were required. If the inside is measured, 14 inches would seem the proper amount. It has been found by experiment that if a piece of straight stock is taken and a line drawn on it through the center, and this piece of stock then is bent and the lengths of the inside, center, and outside lines be measured, the outside line will lengthen considerably as the piece is bent. The inside line will shorten correspondingly, while the center line will remain comparatively unaltered in length. This is universally true, and the proper length of stock required for making any bent shape may always be obtained by measuring the center line of the curve or bend. To return to

the first example: In this case, if the center line of the stock be measured, $7\frac{1}{2}$ inches will be the length for each leg, thus making a total of 15 inches of stock required to make that particular bend. This is a universal rule which should always be followed when measuring stock, to take the length of the center line.

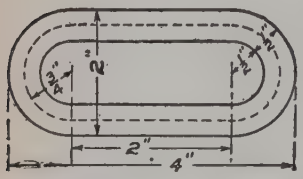


Fig. 55. Diagram for Calculating Stock in Link

Circles. On circles and parts of circles the length of stock may be easily calculated. The circumference, or distance around a circle, is found by multiplying the diameter by $3\frac{1}{7}$ or, more accurately, 3.1416. As an illustration, the stock necessary to bend up the ring in Fig. 54, would be calculated as follows: The inside diameter of the ring is 6 inches and the stock is 1 inch thick. This would make 7 inches the diameter C of the circle made by the center line, which may be called the calculating diameter, and the length of stock required would be $7 \times 3\frac{1}{7}$ or 22 inches.

Links. A combination of circle and straight lines is illustrated in Fig. 55. This link may be divided into two semicircles at the end, with two straight pieces at the sides. The outside diameter of the ends being 2 inches, would leave the straight sides each 2 inches long. The calculating diameter for the ends would be $1\frac{1}{2}$ inches. The total length of stock then required for the ends would be $1\frac{1}{2} \times 3\frac{1}{7} = 4\frac{5}{7}$, or approximately $4\frac{11}{16}$ inches. As each of the straight sides would take 2 inches of stock, the total length required would be $4 + 4\frac{11}{16} = 8\frac{11}{16}$ inches. With a slight allowance for welding, the amount cut should be $8\frac{3}{4}$ inches.

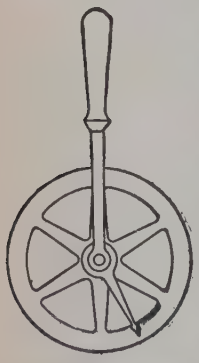


Fig. 56. Measuring Wheel

Measuring Wheel. Another method of measuring stock is by using a measuring wheel such as is shown in Fig. 56. This is simply a light running wheel mounted on a handle with some sort of a pointer attached. The wheel is sometimes made with a circumference of 24 inches and the rim graduated in inches and eighths. To use it, the wheel is placed lightly in contact with the line or object which it is wished to measure, with the zero mark on the wheel corresponding to the point

from which the measurement is started. The wheel is then pushed along the surface following the line to be measured, with just enough pressure to cause it to revolve. By counting the revolutions and parts of a revolution made by the wheel, the required distance may be easily measured.

Measurement by String or Wire. *Scrolls and Irregular Shapes.* Difficult shapes may be measured by either of two methods. The commoner way is to lay the scroll or shape off full size and measure the length by laying on this full-sized drawing a string or thin piece of wire, causing the string or wire to follow the center line of the bent stock. The wire or string is then straightened and the length measured. This is about the easiest and best way of measuring work of this character.

Measurement by Dividers. Another method, which is more practical in the drafting room, consists of using a pair of dividers. The points of the dividers are set fairly close together and the center line is then stepped off and the number of steps counted. The same number of spaces are then laid off along a straight line and the length measured.

Bend Types

Ring and Eye Bending. In making a ring or an eye, the first step of course is to calculate the amount of stock required. In making ordinary rings 4 or 5 inches in diameter, the stock should be heated for about half its length. In starting the bend, the extreme end of the piece is first bent by placing the bar across the horn of the anvil and bending it down as illustrated in Fig. 57. The bar is then pushed ahead and bent down as it is fed forward. The blows should not come directly on top of the horn but should fall outside of the point of support, as illustrated. This bends the iron and does not hammer it out of shape. One half of the circle is bent in this way, then the stock is turned end for end, the other end heated, and the second half bent in the same way as the first, the bending being started from the end as before.

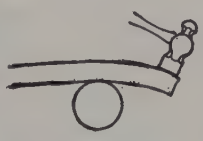


Fig. 57. Starting Eye Bend

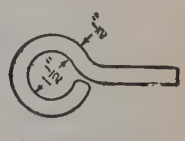


Fig. 58. Finishing Eye Bend

Eye bending is done in a somewhat different manner. Suppose it be required to bend up an eye as shown in Fig. 58. To calculate

the amount of stock required: The diameter in this case to be used is 2 inches, and the amount of stock required 2 inch$\times 3\frac{1}{7}$ inch$=$ $6\frac{2}{7}$ inches, or practically $6\frac{3}{8}$ inches. This distance is laid off by making a chalk mark on the anvil $6\frac{3}{8}$ inches from the end. The iron is

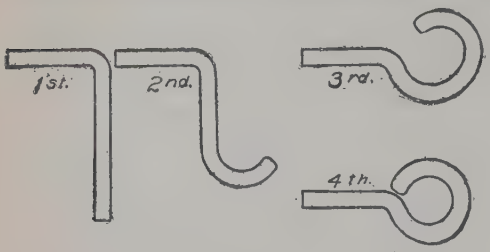


Fig. 59. Successive Steps in Eye Bending

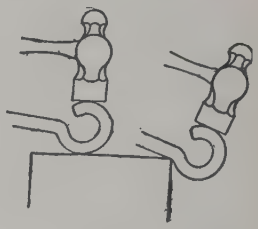


Fig. 60. Closing Up Small Eyes

heated and placed against the anvil with one end on the chalk mark and the other end extending over the end of the anvil. The hand hammer is then held on the bar with one edge at the edge of the anvil, thus measuring off the required distance on the bar. Still holding the hammer on the bar the piece is laid across the anvil, with the edge

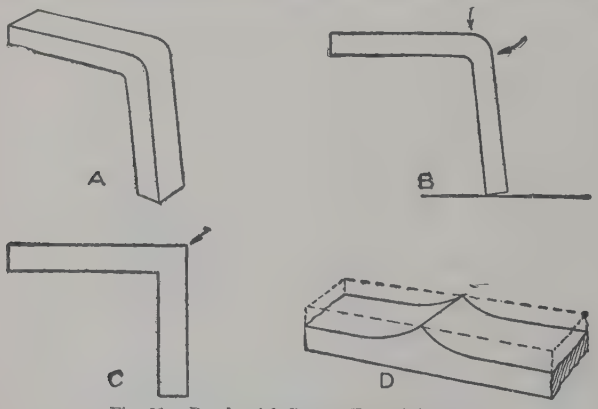


Fig. 61. Bends with Square-Forged Corners

of the hammer even with the edge of the anvil and the $6\frac{3}{8}$ inches extending over the edge or corner. This piece is then bent down into a right angle as shown in the first illustration of Fig. 59. The eye is bent in much the same manner as the ring, except that all the bending is done from one end, the successive steps being shown in the illustration. Small eyes are closed up in the manner shown in Fig. 60.

Bend with Square-Forged Corner. *Upsetting.* Brackets and other forgings are frequently made with the outside corner square and sharp, as shown at *C*, Fig. 61, and, of the two ways of doing this, one method is to use the size of stock required for the sides, first shaping the corner as at *A*. This corner is then squared by upsetting the metal at the bend, the blows coming as shown by the arrows at *B*. The work should rest on the anvil face, and not over one corner, while being hammered.

Drawing Down Large Stock. A second method is to use thicker stock and to draw out the ends, leaving a hump, shown at *D*, where the outside corner of the bend is to come. The dotted lines show the original shape of the bar; the solid lines the shape before bending. Sometimes stock of the size used in the first method is taken and is upset to form the ridge, in place of drawing out the heavier stock.

The first method is the one more commonly used on medium sized work.

Twisted Gate Hook. It should be understood that the description given here will serve not only as a description of the particular

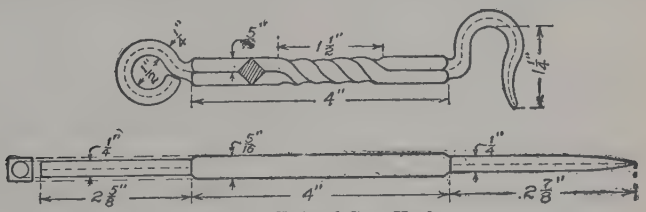


Fig. 62. Twisted Gate Hook

piece in question but also as a general description of a variety of similarly shaped forgings. The methods used may be employed on other forgings of the same general shape.

Fig. 62 shows a twisted gate hook. To start with, it is necessary to determine exactly what lengths the different parts of the hook will have after they are forged to dimensions, and before they are bent to shape. Before bending, the work is first drawn down to size as is indicated in the illustration. The bar is left square in the center for the central part, and each end is drawn to $\frac{1}{4}$ inch round to form the hook and eye ends. The length of stock after being drawn out to $\frac{1}{4}$ inch round, required to make the eye, is $2\frac{3}{8}$ inches. Allowing about $\frac{1}{4}$ inch for the straight part before the eye is reached would make the total amount of stock required for the eye $2\frac{5}{8}$ inches. To

obtain the amount of stock for the hook it is necessary to lay off the hook full size. If the drawing is full-sized, the measuring may be done directly on the drawing, but if not, a rough sketch having the proper dimensions should be laid off and the measuring done on that, the measuring of course being done along the dotted center line. This measuring is done by simply laying a string on the dotted line, then straightening out the string and measuring its length. In this way it will be found that $2\frac{7}{8}$ inches is required by the hook. The first step is then to forge the work into the shape shown in Fig. 62.

Forming Shoulders. The shoulder where the round stock joins the square should be forged in the manner indicated in Fig. 63. The bar is laid across the anvil with the point where the shoulder is wished lying directly on the corner of the anvil. The set hammer is then placed on top of the work in such a way that the edge of the

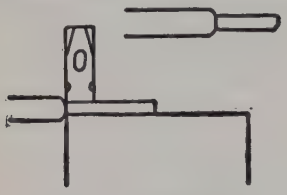


Fig. 63. Forging Shoulder

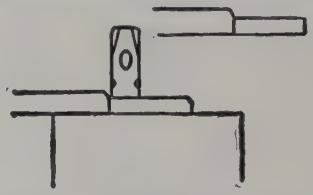


Fig. 64. Making Shoulder Only on One Side

set hammer comes directly in line with the edge of the anvil. The set hammer is then driven into the work with a sledge hammer. The bar should be turned continually or an uneven shoulder will be the result. If a shoulder is wanted on one side only, as illustrated in Fig. 64, it should be worked in as indicated there; that is, one side of the iron should lie flat on the anvil face while the set hammer works down the metal next to the shoulder.

After the two ends of the hook are drawn out, the eye and the hook are bent up into shape. The twist in the center of the hook may be made either by using two pairs of tongs or by twisting in a vise. By the latter method a mark is first made on the vise in such a way that, when the end of the hook is placed even with the mark, the edge of the vise will come at the end of the point where the twist is wanted. The hook should be heated and placed in the vise, the other end being grasped by a pair of tongs in such a way that the distance between the tongs and the vise is just equal in

length to the twist. The twist is made by simply revolving the tongs around. In making a twist of this kind, no allowance need be made in length, as it practically has no effect on the length of the stock.

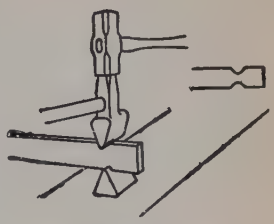


Fig. 65. Starting Solid Eye Bolt

Eye Bolts. Eye bolts are made by two general methods, being either solid or welded. The solid eye bolt is much stronger. A solid eye bolt, or forged eye, as it is sometimes called, may be started in the general manner illustrated in Fig. 65. A nick is made on either side of a flat bar by using top and bottom fullers as illustrated. The end is then rounded up as shown in Fig. 66. Particular attention should be given to seeing that the eye is forged as nearly to a perfect circle as possible before any punching is done. The stock around the eye is rounded up over the horn of the anvil as at *A*, by swinging it back and forth as it is hammered. The hole when first punched is like *B*, but when finished should be like *C*. The other end of the bar is then drawn down to form the round shank. If a very long shank is wanted a short stub shank may be formed in forging the eye and a round bar of the proper size welded on.

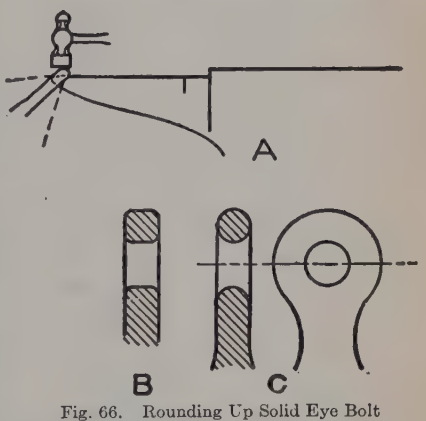


Fig. 66. Rounding Up Solid Eye Bolt

Welded eye bolts may be made in two different ways. The easier method produces an eye shaped as in Fig. 67. To make such a bolt, first scarf the end so that it will fit over the bend of the rod along the dotted line *ab*. Bend the eye over the horn of the anvil. Finally bring to a welding heat and weld in accordance with instructions already given.

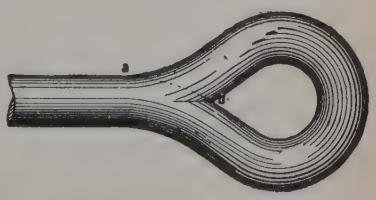


Fig. 67. Welded Eye Bolt

An eye of better appearance, as shown in Fig. 68, is made as follows: Upset the body of the metal as a seat for the scarf at the end, as shown at *a*. Scarf the end of the bar and bend over the

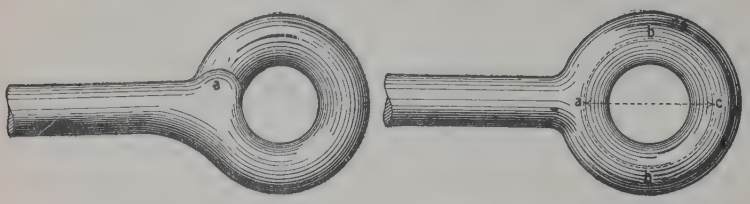


Fig. 68. Eye Bolt of Somewhat Better Form than Fig. 67

horn of the anvil into a true circle to fit the seat at *a*, and then weld as before.

The length of metal required for an eye or ring is nearly equal to the length of the circumference of a circle whose diameter is equal to the mean diameter of the ring. Thus in Fig. 68 the length required for the eye will be approximately the length of the circle *abcb* whose diameter is *ac*.

Chain Hooks. These are made in a variety of shapes and with solid or welded eyes, the general method of making the eyes being exactly as described before under Eye Bolts. A common shape is shown in Fig. 69. The stock is forged into shape similar to Fig. 70 before being bent. To determine the length *A* the drawing is measured in the same way as described in making the gate hook. The weakest point in most hooks is the part lying between the lines marked *xx* in Fig. 69. This part of the hook should be heavier and stronger than the other parts. When a strain is put on the hook, there is always a tendency to straighten out or to assume the shape shown by the dotted lines.

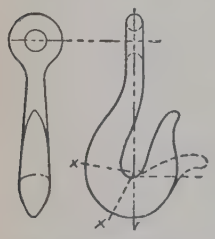


Fig. 69. Chain Hook

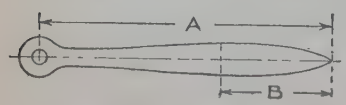


Fig. 70. Hook before Bending

When forging the hook into shape, the dimension *B*, Fig. 70, should be made such that the heaviest part of the hook comes in this weakest point. After the hook is entirely forged to size, it should be bent into shape. Hooks are also made from round and from square iron. When made for hooking over a link, and so

TABLE I
Sizes of Hoisting Hooks

Item	Symbol	Sizes											
Load (tons)	T	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	3	4	5	6	8	10
Stock (inches)	A	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$1\frac{1}{16}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{7}{8}$	$3\frac{1}{4}$

shaped that the throat or opening is just large enough to slip easily over a link edgewise, but too narrow to slip off of this link down to the one which, of course, is turned at right angles, the hook is known as a *grab hook*.

Hoisting Hooks. *Sizes.* A widely accepted shape for hooks of this character used on cranes is shown in Fig. 71. The shape and formulas for the dimensions are given by Henry R. Towne in his "Treatise on Cranes". The size of stock required for a hook to carry any particular load is given in Table I; the load for which the hook is designed being given in the upper line, while the lower line gives the size of the stock to be used in making the hook.

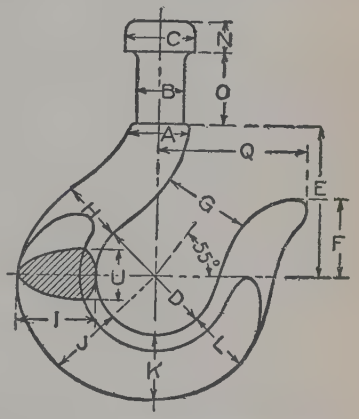


Fig. 71. Details of Hoisting Hook

T = working load (tons of 2,000 pounds)

A = diameter (inches) of round stock used to form hook

The other dimensions of the hook are found by the following formulas, all of the dimensions being given in inches:

$B = .8\ A$	$H = 1.08\ A$
$C = 1.2\ A$	$I = 1.33\ A$
$D = .5\ T + 1.25$	$J = 1.2\ A$
$E = .64\ T + 1.6$	$K = 1.13\ A$
$F = .33\ T + .85$	$L = 1.05\ A$
$G = .75\ D$	$M = .5\ A$
$O = .363\ T + .66$	$N = .85\ B - .16$
$Q = .64\ T + 1.6$	$U = .866\ A$

Illustrative Example. To illustrate the use of the table, suppose it be required to make a hook to raise a load of 500 pounds or one-

quarter of a ton. In the line marked T is found the load $\frac{1}{4}$; directly below it are the figures $\frac{1}{1}\frac{1}{6}$, showing the size of stock to be used. The dimensions of the hook are found as follows:

$D = .5 \times \frac{1}{4} + 1.25 = 1\frac{3}{8}$ inches
$E = .64 \times \frac{1}{4} + 1.6 = 1\frac{3}{4}$ inches (about)
Etc.
$I = 1.33$ $A = 1.33 \times \frac{1}{1}\frac{1}{6} = .915$, or about $\frac{2}{3}\frac{9}{2}$ inch

When reducing the decimals the dimensions which have to do only with the bending of the hook, i.e., the opening, length, length of point, etc., may be taken to the nearest 16th, but the dimensions through the body of the hook or stock should be reduced to the nearest 32nd on small hooks. The completed dimensions of the hook in question, of 500-pound capacity, would be as follows:

$D = 1\frac{3}{8}$ inches	$I = \frac{29}{32}$ inch
$E = 1\frac{3}{4}$ inches	$J = \frac{13}{16}$ inch
$F = \frac{15}{16}$ inch	$K = \frac{25}{32}$ inch
$G = 1$ inch	$L = \frac{23}{32}$ inch
$O = \frac{3}{4}$ inch	$M = \frac{11}{32}$ inch
$Q = 1\frac{3}{4}$ inches	$U = \frac{1}{3}\frac{5}{2}$ inch
$H = \frac{3}{4}$ inch	

Bolts. *Upset-Head Types.* Of the two methods of making bolts, either by upsetting or by welding the heads, the first method is more common on small bolts and machine made bolts. The welded head is more commonly used for heavy hand forged bolts. The upset head is the stronger provided both are equally well made. The size of the bolt is always given as the diameter and length of shank or stem. Thus a bolt known as $\frac{1}{2}$-inch by 6-inch, or $\frac{1}{2}$-inch bolt 6 inches long, would mean a bolt having a shank $\frac{1}{2}$ inch in diameter and 6 inches long from the under side of the head to the end of the stem, having the dimensions of the bolt shown in Fig. 72. The dimensions of the bolt heads are always the same for the same sized bolt, and are determined from the diameter of the shank. The diameter of the head at D, Fig. 72, is the distance

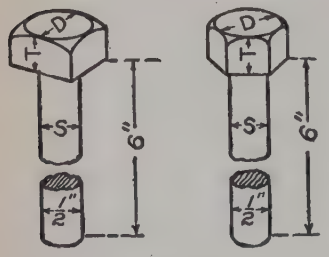


Fig. 72. Bolts with Square and Hexagon Heads

across the head from flat side to flat side, and is known as the *diameter across the flats*. The thickness of the head is taken as shown at T. If S equals the diameter of the shank of the bolt, the dimensions of the head would be as follows:

$$D = 1\tfrac{1}{2} \times S + \tfrac{1}{8} \text{ inch}$$
$$T = S$$

For a two-inch bolt the dimensions would be as follows:

$$\text{Diameter of head } D = 1\tfrac{1}{2} \times 2 + \tfrac{1}{8} = 3\tfrac{1}{8} \text{ inches}$$

The thickness of head T would be equal to diameter of the shank, or 2 inches. These dimensions are for rough or unfinished heads. Each dimension of a finished head is $\frac{1}{16}$ inch less than the same dimension of a rough head. Bolts generally have the top corners of the head rounded or chamfered off. This may be done with a hand hammer; or with a cupping tool, which is simply a set hammer with the bottom face hollowed out into a cup shape.

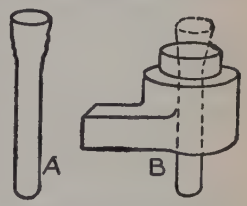


Fig. 73. Upsetting Bolt Heads

Where large quantities of bolts are to be made, the bars are heated in a furnace and headed by special machinery. Where the work is done by hand the tools are of the simplest character. The method of upsetting is shown in Fig. 73. The header consists of a disc in which a hole has been drilled to correspond to the diameter of the bolt. A handle 12 or 15 inches in length is welded to the disc. Such a tool is shown in Fig. 74. The hole should be about $\frac{1}{32}$ inch larger than the nominal size of iron. To make a bolt with this tool: First cut off the iron to the required length; then heat the end to be headed, to a dull straw color; strike the end with a hammer or against the anvil and upset it so that the portion

Fig. 74. Typical Bolt Header

intended for the formation of the head will not pass through the header. Then place the hole of the header over the square hole in the tail of the anvil and drop the cold end of the bolt through it.

Strike the projecting portion of the bar and upset it until the requisite thickness of head is obtained. This will probably leave a head of curved but irregular outline. Remove from the header and square the head thus upset, on the face of the anvil. This will probably thicken the head. Again drop the cold end through the header and strike the head until it is reduced to proper thickness. After which, again square the edges on the face of the anvil. In doing this work, the smith will hold the header in his left hand. The work will be facilitated if a helper assists with a sledge hammer.

There are a number of simple tools in use for clamping the bar while it is being headed so as to avoid the preliminary upsetting.

Welded-Head Type. Bolts of this type are made by welding a ring of square iron around the end of the shank to form the head. The ring is generally bent up on the end of a bar as shown at *A*, Fig. 75, but not welded. This ring is cut off and placed on the end of the shank as shown at *B*. The joint in the ring should be left slightly open to allow for the expansion in welding. The ring is fastened to the end of the shank by striking it on one side and squeezing it against the shank. The bolt is put into the fire, heated to the welding heat, and the head welded up into the required shape. The ring should not be welded round at first, as it is difficult in this way to make a sound joint, there being a much better chance of doing sound work by welding the head directly square or hexagonal as required. No attention need be paid to the joint in the ring as this will take care of itself. Considerable care must be used in taking the welding heat, as all the heat which reaches the joint must pass through the ring and there is a good chance of burning the ring before the shank reaches the welding heat if the heating is not done slowly and carefully.

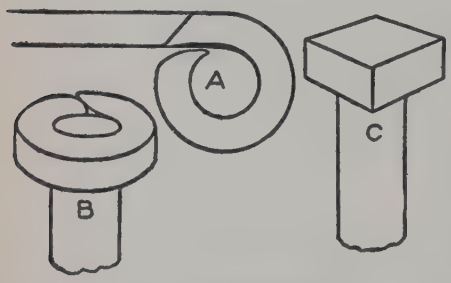


Fig. 75. Welded-Head Bolt

Tongs. Common flat-jawed tongs, such as are used for holding light work, may be made as follows: The stock should be about 1 inch by $\frac{3}{4}$ inch. The first step should be to work the stock down over the edge of the anvil, as shown at *A*, Fig. 76. Turn the flat

side at an angle of about 45 degrees on anvil as shown at *B*, and work down to half the thickness of the jaw hammered out. Then work down the stock on the round horn of the anvil, as shown at *C*. Then

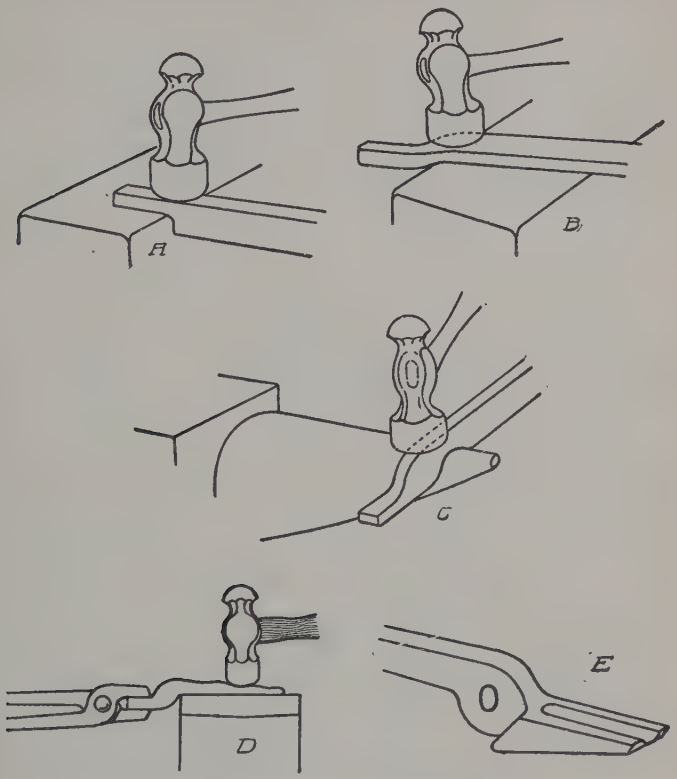


Fig. 76. Steps in Making Flat-Jawed Tongs

draw out the handle, as shown at *D*, allowing enough stock to work out the proper length; or a small amount of stock may be taken, a short stub drawn out, and the round stock welded on, making the proper length as shown in Fig. 77. The last step is to punch the hole for the rivet. It is always a good plan to slightly increase the inside face of the jaw with a fuller, as shown at *E*, Fig. 76, as this insures the jaws gripping the work firmly with the edges, and not touching it simply at one point in the center, as they sometimes do if this crease is not made. The tongs are then riveted together, the

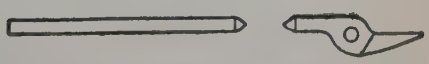


Fig. 77. Welding-On Round Stock

riveting being done with the round end of the hammer; in this way a head is formed on the rivet without upsetting the shank of the rivet very much where it passes through the hole. After riveting, the tongs will probably be stiff or hard to move. They may be loosened up by heating the eye part red hot and moving the handles forward and backward two or three times. They should then be firmly fitted to the work to be handled.

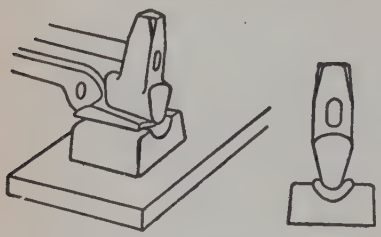


Fig. 78. Method of Making Jaws for Round-Nose Tongs

Tongs for Round Stock. Tongs for handling round stock may be made by the general method described above, the only difference being that after the jaws are shaped, and before riveting together, they should be rounded up as illustrated in Fig. 78, using a fuller and swage as shown.

Light Tongs. Light tongs may be made from flat stock in the manner illustrated in Fig. 79. With a fuller, a cut is made near one end in a piece of flat stock, as at *A*. This end is twisted over at right angles as shown at *B*. Another cut is made on the opposite side, as at *C*, and the end drawn out as indicated by the dotted lines. The tongs are then finished in the usual way. Tongs of this character may be used for very light work and are easily made.

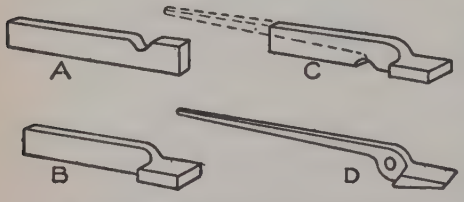


Fig. 79. Light Tongs Made from Flat Stock

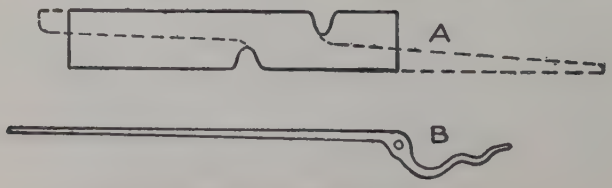


Fig. 80. Method of Forging Pick-Up Tongs

Pick-Up Tongs. Pick-up tongs are made in much the same way as described above, the different steps being illustrated in Fig. 80.

Bolt Tongs. Bolt tongs may be made from round stock, although square may be sometimes used to advantage. The first step is to bend the bar in the shape shown in Fig. 81, which may be

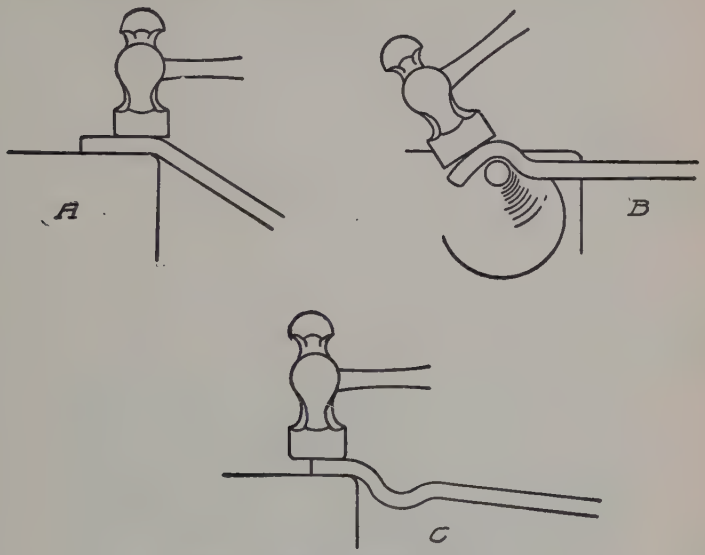


Fig. 81. Steps in Making Bolt Tongs

done by the hammer at the edge of the anvil, shown at *A*, and on the anvil horn as at *B*. The jaw proper is rounded and finished as shown at *C*. The part between the jaw proper and the eye may be worked down into shape by the fuller and set hammer. The finishing may be done as indicated in Fig. 82. The eye and handle are then flattened down and drawn out, the tongs are punched, riveted together, finished, and fitted in the usual manner.

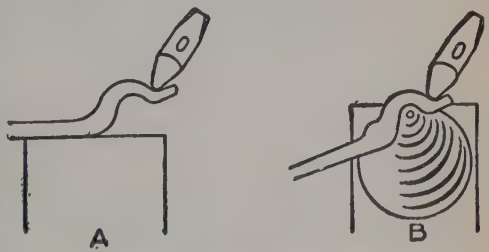


Fig. 82. Finishing Bolt Tongs

Ladles. Ladles similar to the one shown in Fig. 83, may be made from two pieces welded together, one forming the handle, the other the bowl, or as sometimes is done, the handle may be riveted on. A piece of flat stock is first "laid out" as shown in

Fig. 84. This is then cut out with a cold chisel and the handle is welded on at the projecting point. In forming the bowl the stock

Fig. 83. Ladle

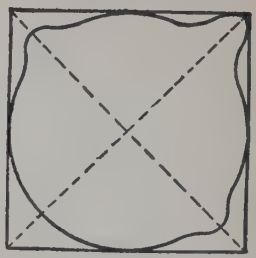


Fig. 84. Flat Stock for Ladle

is heated evenly and placed over a round hole in a swage block or other object—a hole being chosen which is slightly smaller

Fig. 85. Method of Rounding Ladle Bowl

than the outside diameter of the piece to be worked—and to round the bowl it is worked as indicated in Fig. 85, with the peen end of the hammer. The forming should be done as much as possible by working near the edge of the piece rather than in the center. After the bowl has been properly shaped the edges should be ground off smooth and the lips formed as shown in Fig. 86. This is done by placing the part from which the lip is made against one of the small grooves in the side of

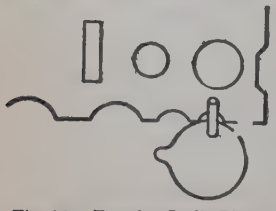


Fig. 86. Forming Ladle Lips

the swage block and driving in a piece of small round iron, thus hollowing out the lip. The stock draws in somewhat when being rounded up. For the bowl of a ladle $3\frac{1}{2}$ inches in diameter, the stock when flat should have an outside diameter of about 4 inches, and be $\frac{1}{8}$ inch thick. Machine steel should be used for making the bowl; if ordinary wrought iron is used, the metal is almost sure to split.

MEDIUM FORGED WORK

Calculation of Stock

Stock Changed in Shape. The calculations made previously for stock, were for stock which was simply bent into shape, the original section or size of the stock remaining unaltered. There is a large variety of work where the shape of the stock is considerably changed, and where it is essential to know the amount required to make a given forging. In doing this kind of work one rule must be remembered, i.e., that the volume of the stock remains unaltered although its shape may be changed. Take as an example the forging shown in Fig. 87, let us determine the amount of stock required to make the piece.

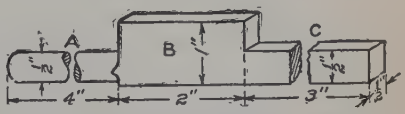


Fig. 87. Diagram for Calculating Stock in Special Forging

The forging is made in the general manner shown in Fig. 88. A piece of stock should be taken large enough in section to make the block *B*, Fig. 87, which will mean that it will be 1 inch wide and $\frac{1}{2}$ inch thick. The metal is worked by making the fuller cuts, as shown in Fig. 88, and then drawing down the ends to the required size, it being, of course, necessary to know the amount of stock required for each end.

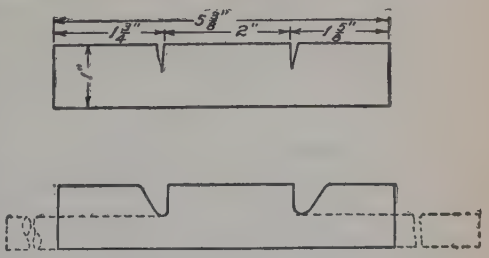


Fig. 88. Steps in Making Forging

For convenience in calculating, the forging will be divided into three parts, the rounded end *A*, the central rectangular block *B*, and the square end *C*, Fig. 87. The stock used being 1 inch by $\frac{1}{2}$ inch, the block *B* will of course require just 2 inches of stock. The

end C would have a volume of $\frac{1}{2}\times\frac{1}{2}\times 3=\frac{3}{4}$ cubic inch. The stock has a volume of $\frac{1}{2}\times 1\times 1=\frac{1}{2}$ cubic inch for each inch of length. The number of inches of stock required for the end C would then be $\frac{3}{4}\div\frac{1}{2}$, or $1\frac{1}{2}$ inches. The end A is a round shaft or cylinder 4 inches long and $\frac{1}{2}$ inch in diameter. To find the volume of a cylinder, multiply the square of the radius ($\frac{1}{2}$ the diameter) by $3\frac{1}{7}$ and then multiply this result by the length of the cylinder. This will give the volume of A as $\frac{1}{4}\times\frac{1}{4}\times 3\frac{1}{7}\times 4=1\frac{1}{14}$, and the amount of stock required to make this piece would be $1\frac{1}{14}\div\frac{1}{2}=1\frac{4}{7}$, which may be taken as $1\frac{5}{8}$ inches. There is, of course, some slight loss due to scaling in working the iron, which must be allowed for. This is generally done by adding a slight amount to the minimum amount required in each case. The amount of stock required in this case would be about

Round shaft A	$1\frac{3}{4}$ inches
Block B	2 inches
Square shaft C	$1\frac{3}{8}$ inches
Total	$5\frac{3}{8}$ inches

When the forging is started, cuts, which are afterward opened up with a fuller, may be made as shown by the upper sketch in Fig. 88. In this particular case it is not absolutely necessary that exactly the proper amount of stock be taken, as it would be a very easy matter to take a little too much and trim off the surplus from the ends, after the forging was made.

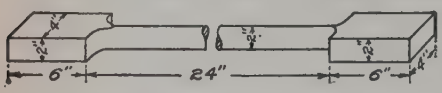


Fig. 89. Diagram of Connecting Rod

With the forging such as shown in Fig. 89, however, it is essential that the exact amount be used. This forging, which is the general shape of a connecting rod, would be started as shown in Fig. 90, and it is quite important that the distance A be correct. The stock used should be 2 inches by 4 inches. Each end will, of course, require just 6 inches of stock. The center part is a cylinder 2 inches in diameter and 24 inches long, the volume of which would be $1\times 1\times 3\frac{1}{7}\times 24=75\frac{3}{7}$ cubic inches, which may be taken as $75\frac{1}{2}$ cubic inches. For each inch in length the 2-inch by 4-inch stock would have a volume of

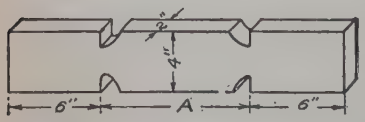


Fig. 90. Starting Connecting-Rod Work

TABLE II

Weight of Flat Rolled Iron

(Length 12 Inches)

Thickness	Width (in.)																				
	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2⅛	2¼	2⅜	2½	2⅝	2¾	2⅞	3
	Weight (lb.)																				
⅛	.208	.260	.313	.365	.417	.469	.521	.573	.625	.677	.729	.781	.833	.885	.938	.989	1.04	1.09	1.15	1.20	1.25
¼	.416	.521	.625	.729	.833	.938	1.04	1.15	1.25	1.35	1.46	1.56	1.67	1.77	1.88	1.98	2.08	2.18	2.29	2.39	2.50
⅜	.624	.781	.938	1.09	1.25	1.41	1.56	1.72	1.88	2.03	2.19	2.35	2.50	2.65	2.81	2.97	3.13	3.28	3.44	3.59	3.75
½	.833	1.04	1.25	1.46	1.67	1.88	2.08	2.29	2.50	2.71	2.92	3.13	3.33	3.54	3.75	3.96	4.17	4.37	4.58	4.79	5.00
⅝		1.30	1.56	1.82	2.08	2.35	2.60	2.86	3.13	3.39	3.65	3.91	4.17	4.43	4.69	4.95	5.21	5.47	5.73	5.99	6.25
¾			1.88	2.19	2.50	2.81	3.13	3.44	3.75	4.06	4.38	4.69	5.00	5.31	5.63	5.94	6.25	6.56	6.88	7.19	7.50
⅞				2.55	2.92	3.28	3.65	4.01	4.38	4.74	5.10	5.46	5.83	6.19	6.57	6.92	7.29	7.65	8.02	8.38	8.75
1					3.33	3.75	4.17	4.58	5.00	5.42	5.83	6.25	6.67	7.08	7.50	7.91	8.33	8.75	9.17	9.58	10.00
1⅛						4.22	4.69	5.15	5.63	6.09	6.56	7.03	7.50	7.97	8.44	8.90	9.38	9.84	10.31	10.78	11.25
1¼							5.21	5.73	6.25	6.77	7.29	7.81	8.33	8.85	9.38	9.89	10.42	10.94	11.46	11.98	12.50
1⅜								6.30	6.88	7.45	8.02	8.59	9.17	9.74	10.32	10.88	11.46	12.03	12.60	13.17	13.75
1½									7.50	8.12	8.75	9.37	10.00	10.62	11.25	11.87	12.50	13.12	13.75	14.37	15.00
1⅝										8.80	9.45	10.14	10.83	11.51	12.19	12.86	13.54	14.22	14.90	15.57	16.25
1¾											10.21	10.94	11.67	12.40	13.13	13.85	14.58	15.31	16.04	16.77	17.50
1⅞												11.72	12.50	13.28	14.06	14.84	15.63	16.41	17.19	17.97	18.75
2													13.33	14.16	15.00	15.83	16.67	17.50	18.33	19.16	20.00
2⅛														15.05	15.94	16.81	17.71	18.59	19.48	20.36	21.25
2¼															16.88	17.80	18.75	19.69	20.63	21.56	22.50
2⅜																18.80	19.79	20.78	21.78	22.76	23.75
2½																	20.83	21.87	22.93	23.96	25.00
2⅝																		22.97	24.07	25.16	26.25
2¾																			25.21	26.35	27.50
2⅞																				27.55	28.75
3																					30.00

$4\times2\times1=8$ cubic inches. Therefore it would require $75\frac{1}{2}\div8=9\frac{7}{16}$ inches of stock, to form the central piece, consequently the distance between the cuts shown at *A* in Fig. 90, will be $9\frac{7}{16}$ inches. To this might be added a slight allowance for loss in scaling. The total amount of stock required would be $6+6+9\frac{7}{16}=21\frac{7}{16}$ inches. Any forging may generally be separated into simple parts of uniform shape as was done above. In this form the calculation may be easily made.

Weight of Forging. To find the weight of any forging the volume may first be found in cubic inches and this multiplied by .2779, the weight of wrought iron per cubic inch. If the forging be made of steel, the figures .2835 should be used in place of .2779. This gives the weight in pounds. Below is given the weight of wrought iron, cast iron, and steel, both in pounds per cubic inch and per cubic foot.

Cast iron	450 per cu. ft.	.2604 per cu. inch
Wrought iron	480 per cu. ft.	.2779 per cu. inch
Steel	490 per cu. ft.	.2835 per cu. inch

Suppose it were required to find the weight of the forging shown in Fig. 87. *A* has a volume of $\frac{1}{1}\frac{1}{4}$ cubic inch, *C* $\frac{3}{4}$ cubic inch, and *B* 1 cubic inch, making a total of $2\frac{1}{2}\frac{5}{8}$ cubic inches. If the forging were made of wrought iron it would weigh $2\frac{1}{2}\frac{5}{8} \times .2779 = .7$ pound. The forging in Fig. 89 has a total volume of $171\frac{3}{4}$ cubic inches and would weigh, if made of wrought iron, 47.64 pounds.

A much easier way to calculate weights is to use tables such as II and III given herewith. Table II gives the weights per foot of flat iron bars. In Table III is given the weights for each foot of length of round and square bars.

When using Table II to ascertain the weight of any size of flat iron per foot of length, look in the first column at the left for the thickness. Then follow out in a horizontal line to the column giving the width. The number given will be the weight in pounds of one foot of the desired size.

To use the table for calculating weights, the procedure would be as follows:

Taking Fig. 89 as an example, each end is 2 inches by 4 inches and 6 inches long, and, as far as the weight is concerned, the two ends would be equal to a bar 2 inches by 4 inches and 1 foot long. From the table it will be seen that a bar 2 inches by 2 inches weighs 13.33 pounds, and a bar 2 inches by 4 inches, being twice as thick would weigh twice that, or 26.66 pounds. A bar 2 inches in diameter weighs 10.47 pounds per foot and, as the central part of the forging is 2 feet long, it will weigh 20.94 pounds, making the total weight of the forging 47.6 pounds.

Finish. Many forgings are machined or finished after leaving the forge shop. The drawings are always made to represent the

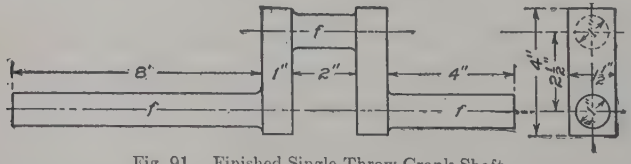


Fig. 91. Finished Single-Throw Crank Shaft

finished work and therefore give the finished dimensions, and it is necessary when this finishing is to be done, to make allowance for it when making the forging, that all parts which have to be finished or machined may be left with an extra metal to be removed in

TABLE III

Weights of Round and Square Rolled Iron

(Length 12 Inches)

Thickness (in.)	Weight (lb.)		Thickness (in.)	Weight (lb.)		Thickness (in.)	Weight (lb.)	
	Square	Round		Square	Round		Square	Round
0			$\frac{17}{16}$	24.08	18.91	$\frac{31}{32}$	96.30	75.64
$\frac{1}{16}$	.013	.010	$\frac{3}{4}$	25.21	19.80	$\frac{63}{64}$	98.55	77.40
$\frac{1}{8}$	.052	.041	$\frac{13}{16}$	26.37	20.71	1	100.8	79.19
$\frac{3}{16}$	.117	.092	$\frac{7}{8}$	27.55	21.64	$\frac{1}{16}$	103.1	81.00
$\frac{1}{4}$	.208	.164	$\frac{15}{16}$	28.76	22.59	$\frac{1}{8}$	105.5	82.83
$\frac{5}{16}$	.326	.256	3	30.00	23.56	$\frac{1}{16}$	107.8	84.69
$\frac{3}{8}$	.469	.368	$\frac{1}{16}$	31.26	24.55	$\frac{3}{4}$	110.2	86.56
$\frac{7}{16}$	.638	.501	$\frac{1}{8}$	32.55	25.57	$\frac{13}{16}$	112.6	88.45
$\frac{1}{2}$	.833	.654	$\frac{3}{16}$	33.87	26.60	$\frac{7}{8}$	115.1	90.36
$\frac{9}{16}$	1.055	.828	$\frac{1}{4}$	35.21	27.65	$\frac{15}{16}$	117.5	92.29
$\frac{5}{8}$	1.302	1.023	$\frac{5}{16}$	36.58	28.73	6	120.0	94.25
$1\frac{1}{16}$	1.576	1.237	$\frac{3}{8}$	37.97	29.82	$\frac{1}{8}$	125.1	98.22
$\frac{3}{4}$	1.875	1.473	$\frac{7}{16}$	39.39	30.94	$\frac{1}{4}$	130.2	102.3
$1\frac{3}{16}$	2.201	1.728	$\frac{1}{2}$	40.83	32.07	$\frac{3}{8}$	135.5	106.4
$\frac{7}{8}$	2.552	2.004	$\frac{9}{16}$	42.30	33.23	$\frac{1}{2}$	140.8	110.6
$1\frac{15}{16}$	2.930	2.301	$\frac{5}{8}$	43.80	34.40	$\frac{5}{8}$	146.3	114.9
1	3.333	2.618	$1\frac{1}{16}$	45.33	35.60	$\frac{3}{4}$	151.9	119.3
$\frac{1}{16}$	3.763	2.955	$\frac{3}{4}$	46.88	36.82	$\frac{7}{8}$	157.6	123.7
$\frac{1}{8}$	4.219	3.313	$1\frac{3}{16}$	48.45	38.05	7	163.3	128.3
$\frac{3}{16}$	4.701	3.692	$\frac{7}{8}$	50.05	39.31	$\frac{1}{8}$	169.2	132.9
$\frac{1}{4}$	5.208	4.091	$1\frac{15}{16}$	51.68	40.59	$\frac{1}{4}$	175.2	137.6
$\frac{5}{16}$	5.742	4.510	4	53.33	41.89	$\frac{3}{8}$	181.3	142.4
$\frac{3}{8}$	6.302	4.950	$\frac{1}{16}$	55.01	43.21	$\frac{1}{2}$	187.5	147.3
$\frac{7}{16}$	6.888	5.410	$\frac{1}{8}$	56.72	44.55	$\frac{5}{8}$	193.8	152.2
$\frac{1}{2}$	7.500	5.890	$\frac{3}{16}$	58.45	45.91	$\frac{3}{4}$	200.2	157.2
$\frac{9}{16}$	8.138	6.392	$\frac{1}{4}$	60.21	47.29	$\frac{7}{8}$	206.7	162.4
$1\frac{1}{8}$	8.802	6.913	$\frac{5}{16}$	61.99	48.69	8	213.3	167.6
$\frac{1}{16}$	9.492	7.455	$\frac{3}{8}$	63.80	50.11	$\frac{1}{4}$	226.9	178.2
$\frac{3}{4}$	10.21	8.018	$\frac{7}{16}$	65.64	51.55	$\frac{1}{2}$	240.8	189.2
$1\frac{3}{16}$	10.95	8.601	$\frac{1}{2}$	67.50	53.01	$\frac{3}{4}$	255.2	200.4
$\frac{7}{8}$	11.72	9.204	$\frac{9}{16}$	69.39	54.50	9	270.0	212.1
$1\frac{15}{16}$	12.51	9.828	$\frac{5}{8}$	71.30	56.00	$\frac{1}{4}$	285.2	224.0
2	13.33	10.47	$1\frac{1}{16}$	73.24	57.52	$\frac{1}{2}$	300.8	236.3
$\frac{1}{16}$	14.18	11.14	$\frac{3}{4}$	75.21	59.07	$\frac{3}{4}$	316.9	248.9
$\frac{1}{8}$	15.05	11.82	$\frac{13}{16}$	77.20	60.63	10	333.3	261.8
$\frac{3}{16}$	15.95	12.53	$\frac{7}{8}$	79.22	62.22	$\frac{1}{4}$	350.2	275.1
$\frac{1}{4}$	16.88	13.25	$\frac{15}{16}$	81.26	63.82	$\frac{1}{2}$	367.5	288.6
$\frac{5}{16}$	17.83	14.00	5	83.33	65.45	$\frac{3}{4}$	385.2	302.5
$\frac{3}{8}$	18.80	14.77	$\frac{1}{16}$	85.43	67.10	11	403.3	316.8
$\frac{7}{16}$	19.80	15.55	$\frac{1}{8}$	87.55	68.76	$\frac{1}{4}$	421.9	331.3
$\frac{1}{2}$	20.83	16.36	$\frac{3}{16}$	89.70	70.45	$\frac{1}{2}$	440.8	346.2
$\frac{9}{16}$	21.89	17.19	$\frac{1}{4}$	91.88	72.16	$\frac{3}{4}$	460.2	361.4
$\frac{5}{8}$	22.97	18.04	$\frac{5}{16}$	94.08	73.89	12	480.	377.

finishing. The parts required to be finished are generally marked on the drawing. Sometimes the finished surfaces have the word *finished* marked on them. Sometimes the finishing is shown simply by the symbol *f*, as used in Fig. 91, showing that the shafts and pin only of the crank are to be finished. When all surfaces of a piece are to be finished the words *finish all over* are sometimes marked on the drawing.

The allowance for finishing on small forgings is generally about $\frac{1}{16}$ inch on each surface. Thus, if a block were wanted to finish 4 inches by 2 inches by 1 inch, and $\frac{1}{16}$ inch were allowed for finishing,

the dimensions of the forging would be $4\frac{1}{8}$ inches by $2\frac{1}{8}$ inches by $1\frac{1}{8}$ inches. On a forging like Fig. 89, about $\frac{1}{8}$ inch allowance would be made for finishing, if it were called for. Thus the diameter of the central shaft would be $2\frac{1}{4}$ inches, the thickness of the ends $2\frac{1}{4}$ inches, etc. On larger work $\frac{1}{4}$ inch is sometimes allowed for machining. The amount of finish allowed depends to a large extent on the way the forging is to be finished. With hand finishing, that is, filing or scraping, $\frac{1}{32}$ inch or even $\frac{1}{64}$ inch is enough; when a lathe or other machine is used, more material should be left.

When a forging calls for finish, in calculating the amount of stock, or the weight, the dimensions taken should not be the actual ones shown by the drawing, but these dimensions with the proper allowance made for finish.

Standard Large Types

Crank Shafts. There are several methods of forging crank shafts. The one more commonly used is the commercial method, as described in detail below. When forgings were mostly made of wrought iron, the cranks were welded up of several pieces. One piece is used for each of the shafts, one piece for each cheek or side, and another piece for the crank pin. Cranks are sometimes bent up out of round stock, but this method is only used on small work.

Common Method of Making. The common method now employed where machine steel is used, is to forge the crank from one solid piece of material. The stock is taken large enough to shape the largest part of the crank without any upsetting. If a crank is required similar to Fig. 91, the size of stock to be used should be $1\frac{1}{2}$ inches by 4 inches in section.

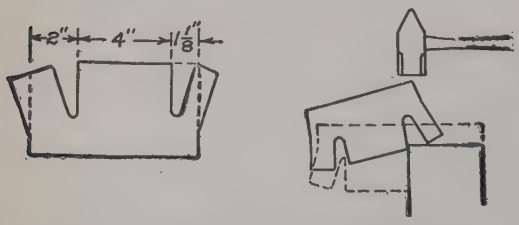


Fig. 92. First Steps in Making Crank Shaft

The first thing to do of course is to calculate the amount of stock required. The long end would contain 10.13 cubic inches. As each inch of stock contains 6 cubic inches, it would require 1.7 inches of stock to form this end, provided there was no waste from scale. Waste does take place, however, and must be allowed for, so about

2 inches of stock should be taken. The short end contains 5.22 cubic inches and would require 0.87 inch of stock, without allowance for scale. About $1\frac{1}{8}$ inches should be taken. The total stock then required would be $7\frac{1}{8}$ inches.

The first step is to make the cuts, and spread the ends as shown in Fig. 92. These ends may then be forged down with a sledge hammer, as illustrated, or may be worked out under the steam hammer, the finishing up against the shoulders being done as illustrated in Fig. 93. The shaft may be rounded down and finished between swages. Care must be taken to see that the cuts are properly spread before drawing out the ends. If the cuts are left without spreading, the metal acts somewhat after the manner shown in Fig. 94. The top part of the bar, as it is worked down, folds over and leaves a crack or cold-shut as illustrated. When the metal starts to act in this way the fault should be corrected by trimming off the overlapping corner along the dotted line shown in the upper sketch.

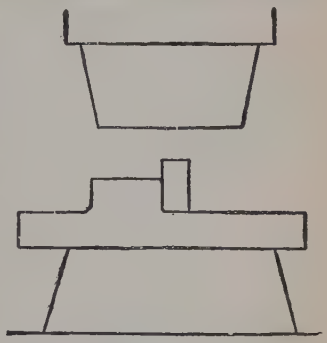


Fig. 93. Finishing Up Shoulder

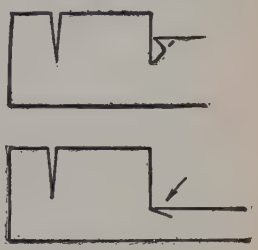


Fig. 94. Results of Improper Spreading

When the forging leaves the shop, it will be left in a shape similar to that shown by the solid lines in Fig. 95, the dimensions shown here allowing for the necessary finishing. The crank itself would be left in a solid block, the throat being afterwards cut out as indicated by the dotted lines. A line of holes is first drilled as shown,

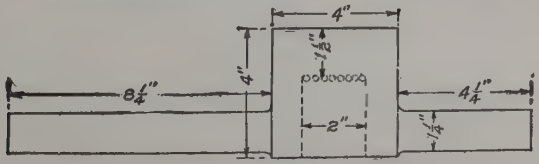


Fig. 95. Crank-Shaft Forging Ready for Machining

and the block of metal to be taken out is removed by making two slits with a cold saw and the block then knocked out with a sledge hammer. It is possible to form this throat by chopping out the

surplus metal with a hot chisel in the forge shop, but on small cranks in particular, such as here shown, it is generally cheaper in a well equipped shop to use the first method.

Multiple-Throw Cranks. When a crank shaft has more than one crank or crank pin, it is spoken of as a multiple-throw crank; a

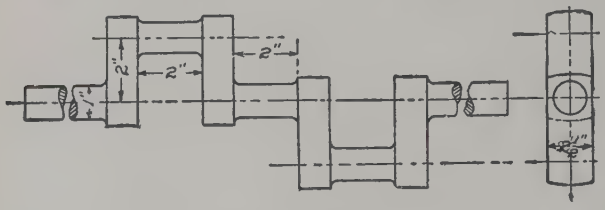


Fig. 96. Finished Double-Throw Crank Shaft

double-throw crank is a crank shaft with two cranks; a three-throw or triple-throw, one with three cranks; etc. As a general rule, multiple-throw cranks are forged flat, i.e., the cranks are all forged in line with each other. The shafts and pins are then rough turned and the cranks are heated and twisted into shape. The forging for the double-throw crank shown finished in Fig. 96 would first be made in the general shape shown in Fig. 97. The parts shown by the dotted lines would then be cut out with a drill and saw as described above, and the shafts and pins rough turned, i.e., turned round, but left as large as possible. The forging is then returned to the forge shop where it is heated and the cranks twisted to the desired angle. When twisting, the crank would be gripped just to the right of the point marked *A*. This may be done with a vise, or a wrench if the crank is small, or it may be held under the steam hammer. The twisting may be done with a wrench similar to that shown in Fig. 98, which may be easily made by bending up a U of flat stock and welding on a handle.

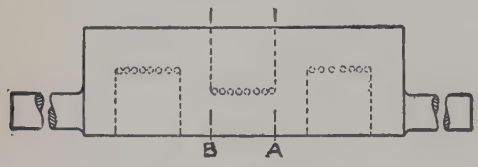


Fig. 97. First Step in Making Double-Throw Crank Shaft

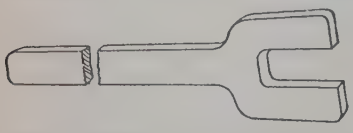


Fig. 98. Wrench for Crank Twisting

Three-Throw Crank. A three-throw crank without any inter-

mediate bearings is shown in Fig. 99. The rough forging for this is shown in Fig. 100. The extra metal is removed, as indicated by the dotted lines, and the twisting is done as described before.

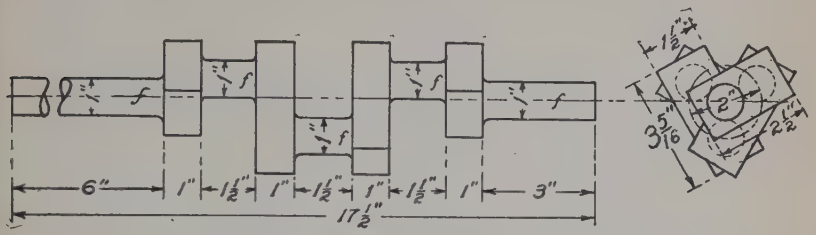


Fig. 99. Diagram of Finished Three-Throw Crank Shaft

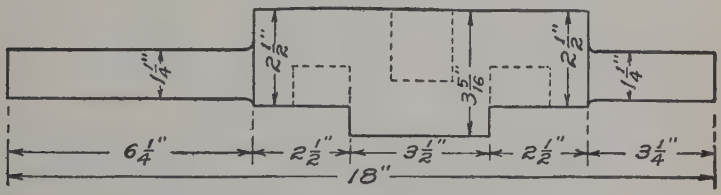


Fig. 100. Three-Throw Crank Forging Ready for Machining

Weldless Rings. Rings and eyes forged solid without any welds may be made in the general manner described below. As an example, suppose it be required to make a ring such as illustrated in Fig. 101. It is necessary, of course, to calculate the amount of stock required. This may be done as follows: The first step is to determine the area of the ring, which is done by taking the area of the outside circle, and subtracting from it the area of the inside circle, as follows:

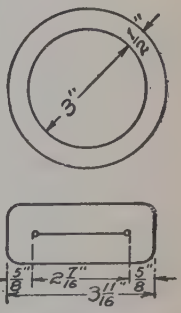


Fig. 101. Weldless Ring

Outside circle area	12.57 sq. in.
Inside circle area	7.07 sq. in.
Ring area	5.50 sq. in.

The stock used when making small thin rings should be twice the width of the side of the ring to which is added at least ¼ inch. A flat bar is first forged rounding on the ends, punched and split as shown; this split is opened out and the ring is hammered into shape. When the bar is split the stock is more or less deformed and when

worked back into shape is slightly thinned. Although no stock is lost by the hammering, an allowance must be made for the thinning and stretching and it is necessary to make the stock slightly wider on this account, as noted above. Allowing $\frac{1}{2}$ inch for hammering, and taking stock $1\frac{1}{2}$ inches wide, the amount of stock required would be $5.5 \div 1.5$, equal to 3.66 inches. Allowing a small amount for loss by scale, etc., $3\frac{11}{16}$ inches of stock should be taken. In making this calculation, the thickness of the stock is not taken into consideration, as the thickness of the finished ring is the same as the stock. This general method is used on a large variety of work, particularly where rings are to be made of tool steel and should be made without a weld.

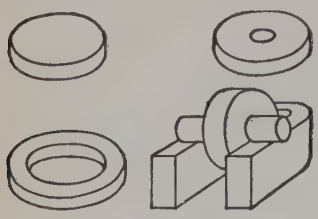


Fig. 102. Weldless Ring Made under Steam Hammer

Another method of making weldless rings, under the steam hammer, is illustrated in Fig. 102. The proper amount of stock is first forged into a disc, a hole is punched into this disc and a mandrel inserted. A U-shaped rest is then placed on the anvil of the steam hammer and the mandrel laid on this. The ring is turned on the mandrel and forged into shape. Larger and larger mandrels are substituted as the hole in the ring increases in size.

Lever with Boss. Taking as an example the forging shown in Fig. 103, the following description will serve for many forgings of the same general shape. There are two general ways of making work of this character. One is to take stock of the proper size for the lever and to weld on a chunk for the boss. The other is to take stock large enough to form the boss and to draw out either the entire lever,

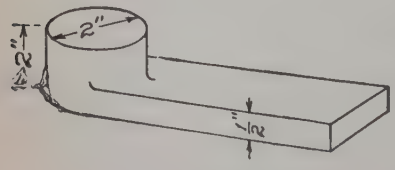


Fig. 103. Lever with Boss

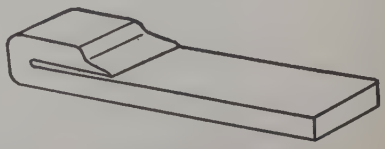


Fig. 104. Stock Bent for Forging Boss

or a short stub, to which the lever is welded. The work may be started for the first method by bending over the end of the stock as illustrated in Fig. 104. This is welded up and rounded by the same

general method as afterward described for the other boss. The second method of shaping is illustrated in Fig. 105. The stock in this case would be 2 inches square. The fuller cut is first made as illustrated at *A*. The end is then drawn out into the shape shown at

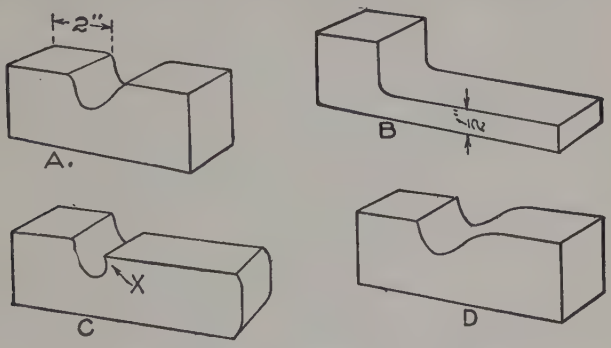


Fig. 105. Method of Shaping Lever with Boss

B. In drawing out the stock, if the metal be allowed to flatten down into shape like *C*, a cold-shut will be formed close to the boss, as the corner at *X* will overlap and work into the metal, making a crack in the work. The proper way to draw out the stock is shown at *D*. The square piece left for the boss is rounded up over the corner of the anvil as shown in Fig. 106. Sometimes to make the work easier

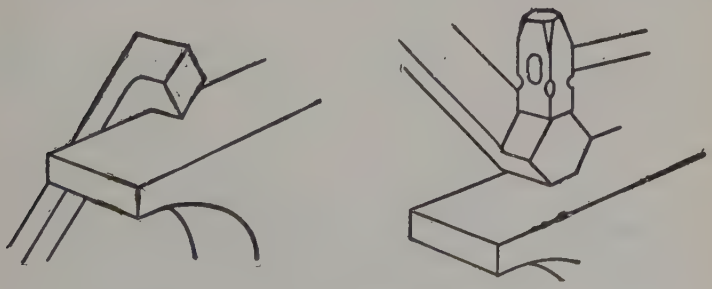


Fig. 106. Rounding-Up Boss

to get at, the end is bent back out of the way and straightened after the forging is completed. The boss may be smoothed up by using a set hammer or swage in the manner indicated.

Knuckles. One example of a very numerous class of forgings is shown in Fig. 107. This is the shape used for what are known as marine ends of connecting rods, knuckle joints on valve rods, and

various other pieces. A common method employed to make such a forging is shown in Fig. 108. Two fuller cuts are first made as indicated at *A* and the part for the shaft of the forging drawn out. The thick end is then punched and split, as indicated at *B*. This split end is opened up and forged out in the manner indicated in Fig. 109, if the work is done on the anvil. Fig. 110 illustrates the method of working out under the steam hammer, the end being first flattened as indicated and then gradually tipped up to the position shown by the dotted lines. When drawn to size, the ends are flattened out straight across and the finishing done around the shank with a fuller, as indicated in Fig. 111. The forging is then bent into a U-shaped loop of approximately the shape of the finished knuckle. A bar of iron the same dimension as the inside of the finished knuckle is inserted between the sides of the loop, and the sides closed down flat, as shown in Fig. 112. Fig. 113 shows other forgings which may be shaped by this same general method. Trim *E*, Fig. 108, to the dotted line.

Fig. 107. Knuckle

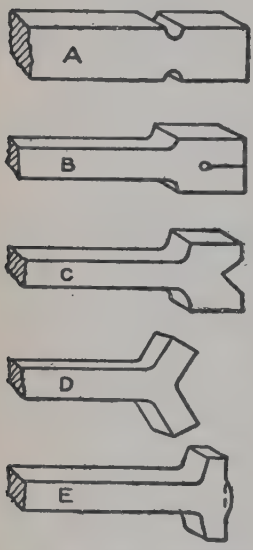


Fig. 108. Method of Making Knuckle

Wrenches. *S-Wrench.* A simple tool that is frequently called for is the S-wrench. This wrench is usually made with a gap at each end suited for nuts of different sizes. It is shown complete in Fig. 114. The jaws at the end should be parallel with each other. A line drawn from one pair of jaws to the other should make an angle of 30 degrees with the center line of each. There are two ways in which such a wrench can be forged. One is to forge the jaws separately and then weld to the handle. In the other the jaws are cut from a solid piece of metal and the iron between is then drawn down to the proper size for the handle. The latter is preferable, since it avoids all welds.

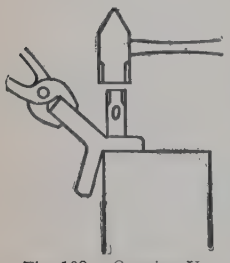


Fig. 109. Opening Up

To make the wrench by the second process, select a piece of steel large enough to form the head. Fuller it down back of the head as shown in *A*, Fig. 115, at *a a*. Round the end and punch the hole *b*. Next treat the other end in the same way and draw out the inter-

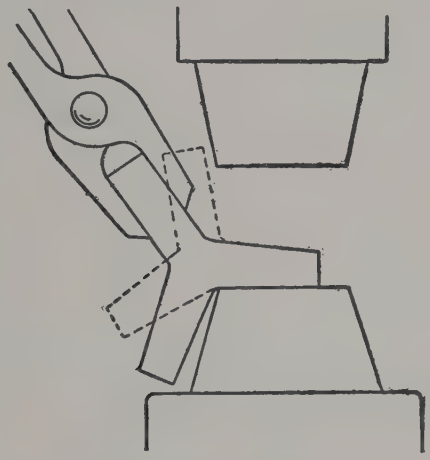


Fig. 110. Working Out Knuckle under Steam Hammer

mediate metal giving the form shown at *B*. Now cut out the holes *b b* securing the form shown at *C*. It now remains to bend the heads to the proper angle and to give the desired curve to the shank. In forging such a wrench the outer edges should be slightly rounded so

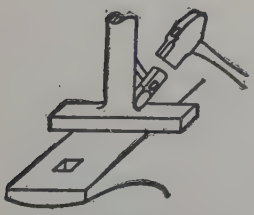


Fig. 111. Finishing Knuckle around Shank

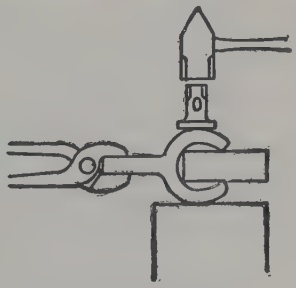


Fig. 112. Closing Sides of Knuckle

that they will not cut the hand. The inside of the jaws should be perfectly square with the sharp edges; this finish can best be obtained by filing.

Socket Wrench. Socket wrenches are made in several ways. The easiest way in "hurry-up" work is the method illustrated in

Fig. 116. A stub is forged to the same size and shape as the finished hole is to be, and a ring, bent up of thin flat iron, welded around

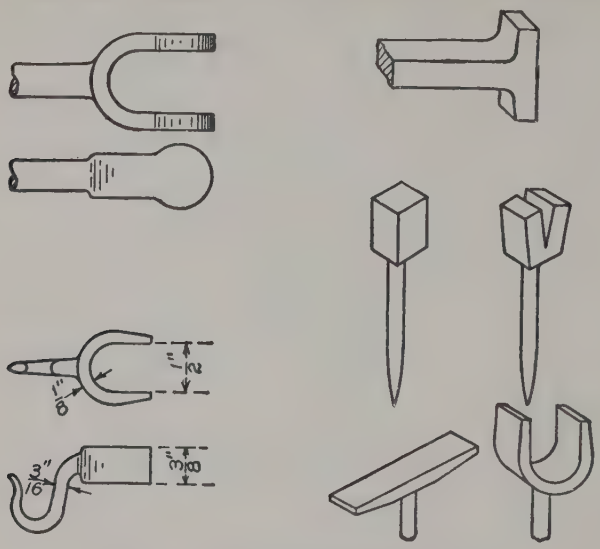


Fig. 113. Typical Shapes Similar to Knuckles

this stub. When finishing the socket, a nut or bolt head of the same size as that the wrench is intended to fit should be placed in the hole and the socket finished over this, between swages. A better way of

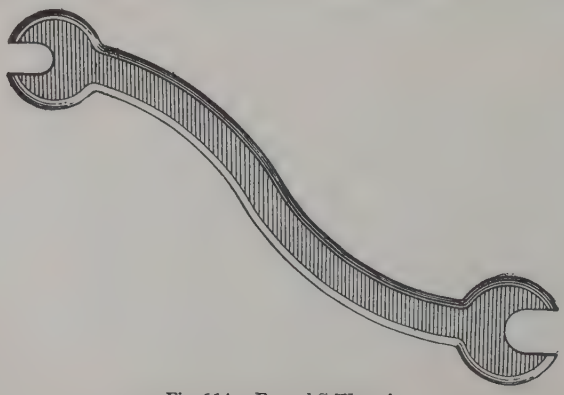


Fig. 114. Forged S-Wrench

making wrenches of this kind is to make a forging having the same dimensions as the finished wrench with the socket end left solid. The socket end is then drilled to a depth slightly greater than the

socket is wanted. The diameter of the drilled hole should be, as shown in Fig. 117, equal to the shortest diameter of the finished hole. After drilling, the socket end is heated, and a punch of the same

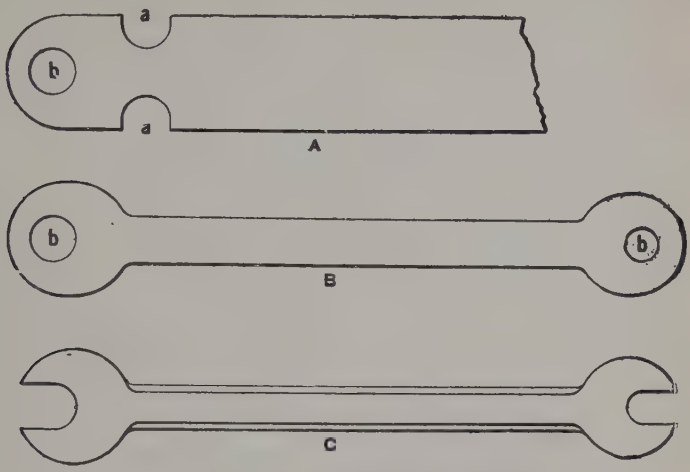


Fig. 115. Steps in Making Wrench

shape as the finished hole is driven into it. The end of the punch should be square across and the corners sharp. As the punch is driven in, it will shave off some of the metal around the corners of

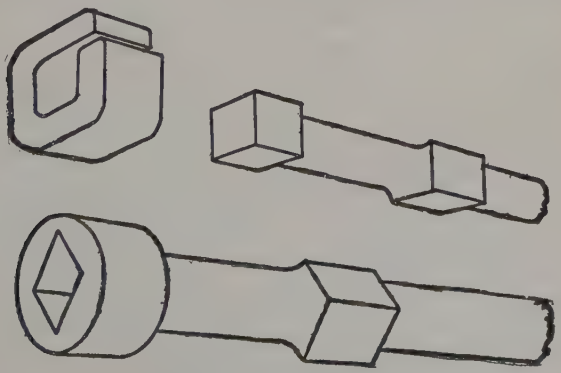


Fig. 116. Socket Wrench

the hole and force it to the bottom, thus making it necessary to have the drilled hole slightly deeper than the finished socket.

Ladle Shank. The ladle shank shown in Fig. 118 may be made in several ways. The ring may be welded up of flat stock and a

round handle welded on with a T-weld, or square stock may be taken, worked out, and split as shown in Fig. 119, these split ends being afterward welded to make the ring. Another method of making without any welds at all would be to split the stock as indicated in Fig. 120 and to work out in the same way that a weldless ring is made. The latter method would take more time but would make the sounder forging.

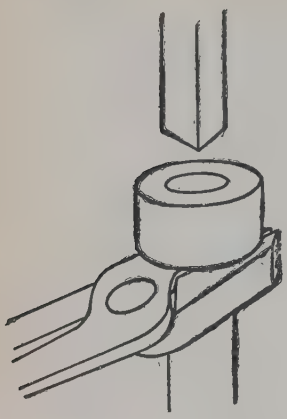


Fig. 117. Making Hole in Socket Wrench

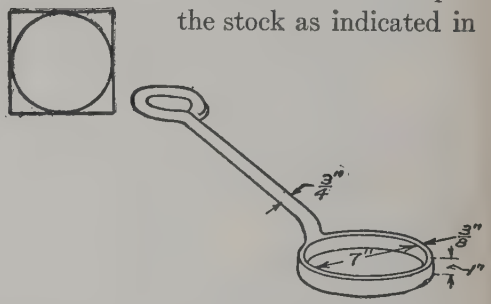


Fig. 118. Ladle Shank

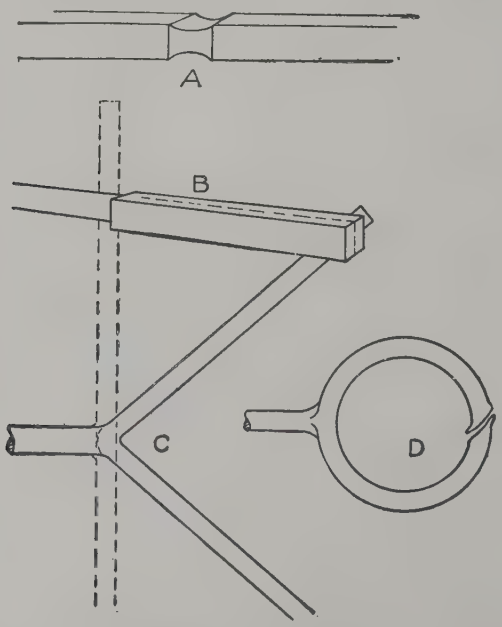


Fig. 119. Ladle Shank Made from Square Stock

Molder's Trowel. The molder's trowel illustrated in Fig. 121 is a sample of a large class of forgings, having a wide thin face with a comparatively small thin stem forged at one end. The stock used for the trowel would be about $\frac{1}{4}$ inch by 1 inch. This is thick enough to allow for the formation of a ridge at *R*. Fig. 122 shows the general method employed. Two nicks are first made with fullers, as illustrated at *A*, and the stem drawn down, roughly, to size. This stem is then bent up at right angles and forged to a square corner, as illustrated at *B*, in the same general manner as the square corner of a bracket is formed. When flattening out the blade in order to leave the ridge shown at *R*, Fig. 121, the work should be held as shown at *C*, Fig. 122. Here the handle is held pointing downward and against the side of the anvil. By striking down on the work and covering the part directly over the edge of the anvil with the blows, all the metal on the anvil will be flattened down. By swinging the piece around into a reversed position, the other edge of the blade is then thinned down. This leaves the small triangle shown by the dotted lines unworked and forms the ridge shown at *R*. The same result could be obtained by placing the work flat on the anvil face and using a set hammer.

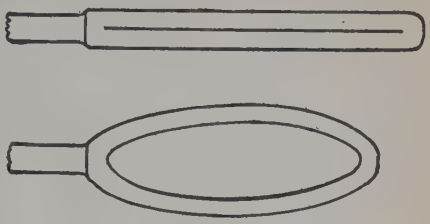


Fig. 120. Ladle Shank without Weld

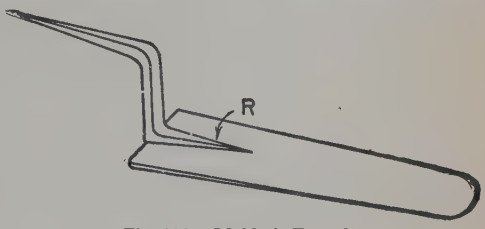


Fig. 121. Molder's Trowel

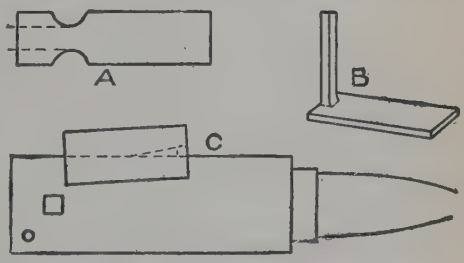
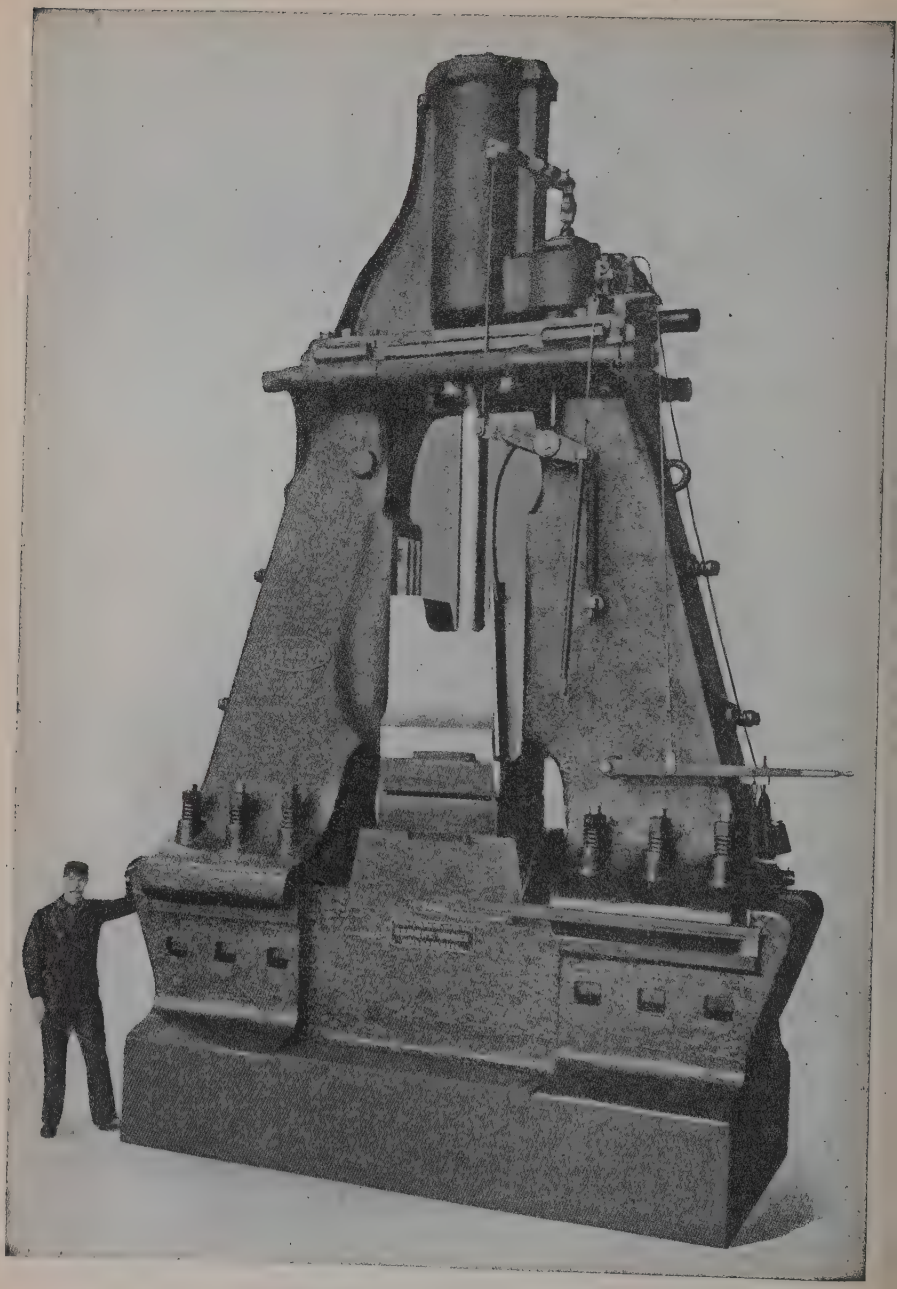


Fig. 122. Method of Making Molder's Trowel



BEMENT STEAM DROP HAMMER
Courtesy of Niles-Bement-Pond Company, New York

FORGING

PART II

FORGING OPERATIONS—(Continued)

TOOL-STEEL WORK

Tool Steel. Although not strictly true technically, for ordinary purposes tool steel may be considered simply a combination of iron and carbon. The more common grade contains perhaps 1 per cent of carbon. Machine steel and wrought iron do not contain this element carbon to any great extent. If a piece of wrought iron or machine steel is heated red hot and then suddenly cooled, the metal remains practically as it was before heating, but if a piece of tool steel be subjected to this treatment, it becomes very hard and brittle. By a modification of this heating and cooling, almost any degree of hardness may be imparted to the steel.

Proper Forging Heat. Before attempting any work with tool steel, a piece of scrap steel is to be experimented with, heated and hardened several times at various heats until the manipulator is sure of the effect of the various heats upon the grain of the steel. The steel should also be experimented with to determine just how high a heat it will stand. When heavy forging is to be done, i.e., when the first rough shaping is done upon a tool, a comparatively high heat should be used. The steel should be forged at about what might be called a good yellow heat. The lighter hammering, when finishing, should be done at a lower heat, about the hardening heat, though very little, if any, hammering should be done below that point. If the grain of the steel has been raised by too high a heat, it can generally be quite decidedly reduced by a little hammering at some heat above the hardening temperature.

Standard Forms

Cold Chisels. The stock should be heated to a good yellow heat and forged into shape and finished as smoothly as possible. When properly forged, the end or cutting edge projects as shown at *C* in

Fig. 123. It is a good plan to simply nick this end across at the point where the finished edge is to come, and then, after the chisel has been tempered, this nicked end may be broken off and the grain examined. Whenever possible, it is a good plan to leave on a tool

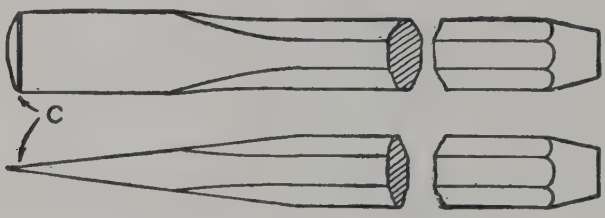


Fig. 123. Typical Views of Cold Chisel

an end of this sort that may be broken off after the tempering is done. When hardening, a chisel should be heated red hot about as far back from the cutting edge as the point *A*, Fig. 124. Care must be taken to heat slowly enough to keep the part being heated at a uniform temperature throughout. If the point becomes overheated, it should not be dipped in water to cool off, but should be allowed to cool in the air to below the hardening heat and then reheated more carefully. When properly heated, the end should be hardened by dipping in cold water to the point *B*. As soon as the end is cold, the chisel should be withdrawn from the water and the end polished bright by rubbing with a piece of emery paper. The part of the chisel from *A* to *B* will still be red hot and the heat from this part will gradually reheat the hardened point. As this cold part is reheated, the polished surface will change color showing at first yellow, then brown, and at last purple. As soon as the purple (almost a blue color) reaches the nick at the end, the chisel should be completely cooled. The waste end may now be snapped off and the grain examined. If the grain is too coarse, the tool should be rehardened at a lower temperature, while if the metal is too soft, and the end bends without breaking, it should be rehardened at a higher temperature.

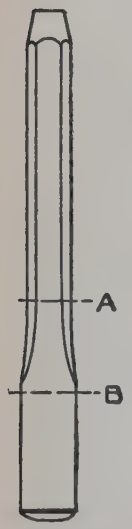


Fig. 124. Heating and Hardening Areas

Cape Chisel. This is a chisel used for cutting grooves, key-seats, etc. The end *A*, Fig. 125, should be wider than the rest of the

blade back to *B*. The chisel is started by thinning down *B* with two fullers, or over the horn of the anvil as shown at *A*, Fig. 126. The

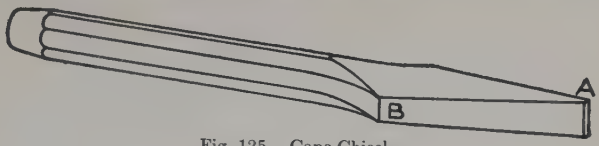


Fig. 125. Cape Chisel

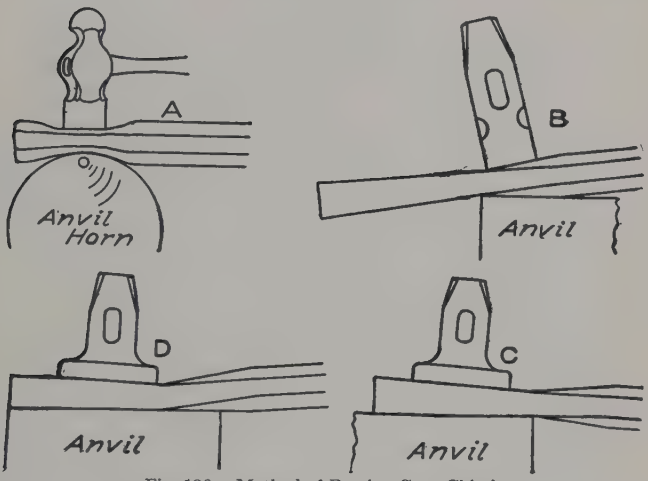


Fig. 126. Method of Forging Cape Chisels

end is then drawn out and finished with a hammer or flatter in the manner illustrated at *B*. A cape chisel is given the same temper as a cold chisel.

Square- and Round-Nose Chisels. These two chisels, the ends of which are shown in Fig. 127, are forged and tempered in practically the same way as the ordinary cape chisel, the only difference being in the shape of the ends. Round-nose cape chisels are sometimes used for centering drills and are then known as *centering chisels*.

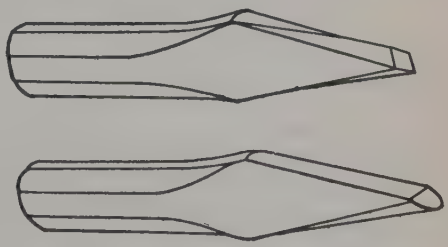


Fig. 127. Square-Nose and Round-Nose Chisels

Lathe Tools. The same general forms of lathe tools are used in nearly all shops, but the shapes are altered somewhat to suit individual tastes.

Right-Hand and Left-Hand Tools. Many lathe tools are made in pairs and are called right-hand and left-hand tools. If a tool is made in such a way that the cutting edge comes toward the left

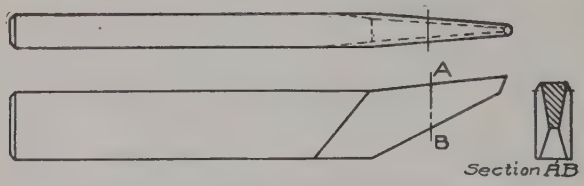


Fig. 128. Views of Lathe Tool Showing Clearance

hand as the tool is held in position in the lathe, it is known as a right-hand tool, i.e., a tool which begins a cut at the right-hand end of the piece and moves from right to left. The one commencing at the left-hand end and cutting toward the right would be known as a left-hand tool. The general shape of the right-hand and left-hand tools for the same use is generally the same excepting that the cutting edges are on opposite sides.

Clearance. When making all lathe tools, care must be taken to see that they have proper clearance, i.e., the cutting edge must project beyond or outside of the other parts of the tool. In other words, the sides of the tool must be undercut or slant downward and backward away from the cutting edge. This is illustrated in the section *AB* of Fig. 128, where the lower edge of the tool is made considerably thinner than the upper edge, in order to give the proper clearance.

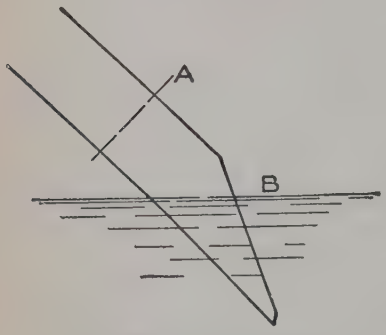


Fig. 129. Tool Hardening

Round-Nose and Thread Tools. These tools are practically alike, excepting for a slight difference in the way the ends are ground. The general shape is shown in Fig. 128. When hardening, the tools should be heated about as far as the line *A*, Fig. 129, and cooled up to the line *B*. The temper is then drawn in the same general way as described for tempering of cold chisels, excepting that when a light yellow

color shows at the cutting edge the tool is cooled for the second time. All lathe tools are given practically the same temper. Sometimes tools are left much harder. In one quite well known plant the tools are simply reheated until the water evaporates from the cutting end, indicating a reheating to a temperature of about 200° Fahrenheit.

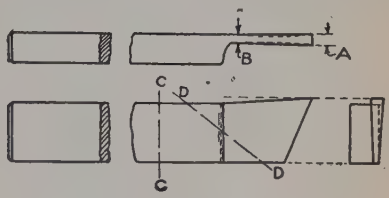


Fig. 130. Typical Cutting-Off Tool

Cutting-Off Tool. Cutting-off tools are forged with the blade either on one side or in the center of the stock. The easier way to make them is to forge the blade with one side flush with the side of the tool, as shown in Fig. 130. For use in a lathe the tool is generally forged on the left side so as to leave the cutting blade straight on the side toward the face plate of the lathe. For planer work, tools are often made in the center of the steel. The cutting edge, the extreme tip *A*, of the blade, should be wider than any other part of the thinned part *B*, in other words, this edge should have clearance in all directions as indicated in the drawing. The clearance angle at the end of the tool, as shown in the sketch, is generally about 20 degrees.

For hardening, heat very little of the steel except the blade; the end of the tool should be heated about as far as *CC*, and cool to

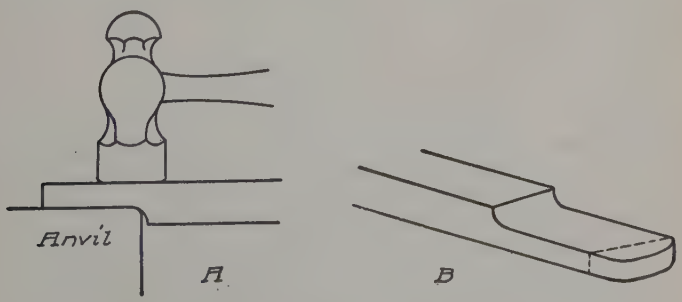


Fig. 131. Method of Forging Cutting-Off Tool

about the line *DD*, enough so that the heat left in the steel will not work toward the point of the tool too quickly. This heat which is left in the steel is for tempering or drawing, and care should be taken so as not to leave the tool hard at the section *B*, as here not

hardness, but toughness, is required. Temper generally to dark straw color or about 430° Fahrenheit.

The tool is started by placing enough of the steel on the anvil to draw out to the length wanted. Part of the face of the hammer is extended a little over the side of the anvil, as shown at *A*, Fig. 131. After roughly shaping, the end is trimmed off with a hot chisel along the dotted lines shown at *B*.

Boring Tool. The general shape of this tool is shown in Fig. 132. The length of the thin end depends upon the depth of the hole in

Fig. 132. Typical Boring Tool

which the tool is to be used and as a general rule should be made as short and thick as possible, in order to avoid springing. The tool may be started in the same general way as the cutting-off tool, the fuller cut being made on the edge of the stock instead of on the side. The cutting edge of the tool is at the end of the small nose, and this nose is the only part which should be tempered.

Diamond Point. In Fig. 133 is shown the general shape of diamond points, and in Fig. 134 the different steps of making them.

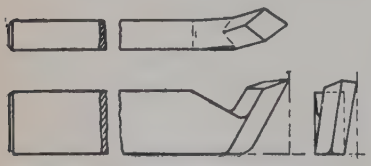


Fig. 133. Typical Diamond Point Tool

The shape is started by using a bottom fuller, working the stock down about one-third, as shown at *A*. The rounded edge of the anvil can also be used in place of the fuller. Work down the point as shown at *B*, turning on the side as shown at *C* for starting the diamond shape, and working both sides until the proper size and shape are obtained. Then, placing the tool point on the flat side on the anvil, use a hot chisel to cut the point to the proper length, shown at *D*. In cooling this tool for hardening, leave but little heat in the rear end of the steel so as to draw slowly to light straw color, or about 410° Fahrenheit for even temperature, which means an even hardness in the point.

Side Tool. Side tools are generally started by drawing down a point endwise, as at *A* in Fig. 135. Hammer the point out at the corner of the anvil so that it can be drawn down small without striking the corner of the hammer into the anvil. Then bring the tool to the flat horn of the anvil for sharpening or drawing out thin on one side, as the top edge. Let part of the face of the hammer extend over the corner of the anvil so as to get the side hammered on the flat, with the recess all on the side that is down, as at *B;* then, placing

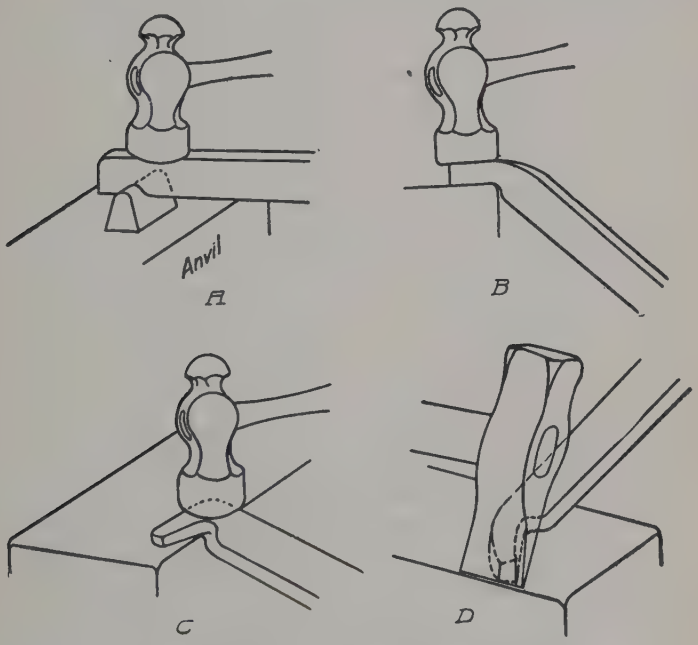


Fig. 134. Method of Forging Diamond Point

the tool on the anvil as at *C*, bend the top edge over to get the proper side clearance, as shown at *E*.

Hardening should be done by placing the tool blade in the cooling tank, as at *D*, and cooling off so as not to leave too much heat, causing the temper to come slowly. The tool is taken from the water, quickly rubbed bright on the flat side, and the temper drawn until the cutting edge shows a light yellow. The same color should show the entire length of the cutting edge. If the color shows darker at one end, it indicates that that end of the blade was not cooled enough, and the tool should be rehardened, this time dipping

in such a way as to bring deeper in the water that end of the blade which was too soft before.

Centering Tool. The centering tool shown in Fig. 136 is used for starting holes on faceplate and chuck work. The end may be

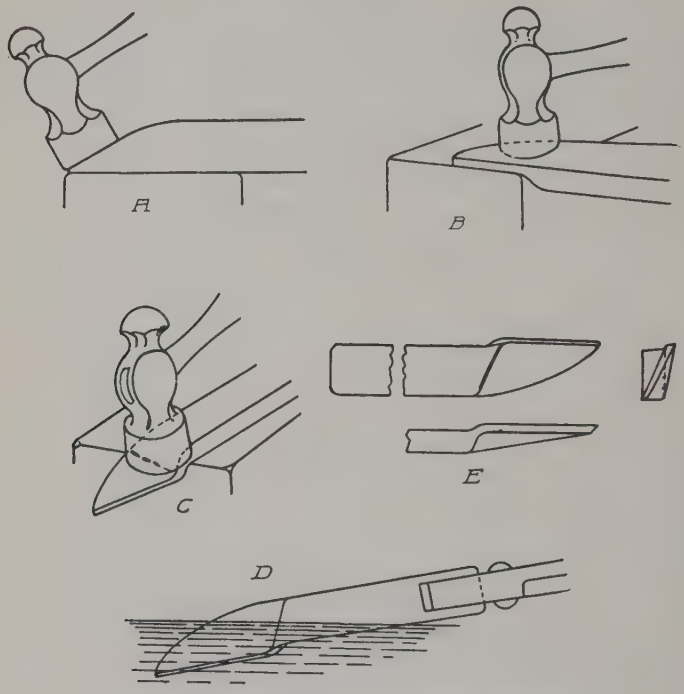


Fig. 135. Method of Forging and Hardening Side Tool

shaped by making a fuller cut and then flattening out the metal, trimming the cutting edge to shape with the hot chisel.

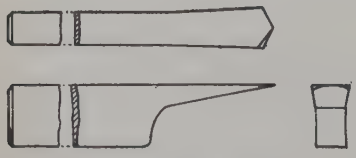


Fig. 136. Centering Tool

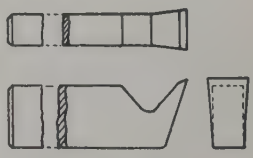


Fig. 137. Finishing Tool

Forming Tools. Forming tools for turret lathes are sometimes forged up in the same general shape as above and tempered like other lathe tools.

Finishing Tool. This tool, Fig. 137, may be started either with a fuller cut or in the same way as the diamond point. The end is then flattened out and shaped with a set hammer as shown in Fig. 138. This generally leaves the end bent out too nearly straight, but it may be easily bent back into shape as indicated at *B*. This bending will probably leave the point something like *C*. A few blows of the hammer at the point indicated by the arrow will give the tool the shape as at *D*. The cutting edge should be tempered the same as for other lathe tools. For planer and shaper tools of this shape, the end should be more nearly at right angles to the edge of the tool, making an angle of about 6 or 8 degrees less than the perpendicular; in other words, the tool should have less end rake.

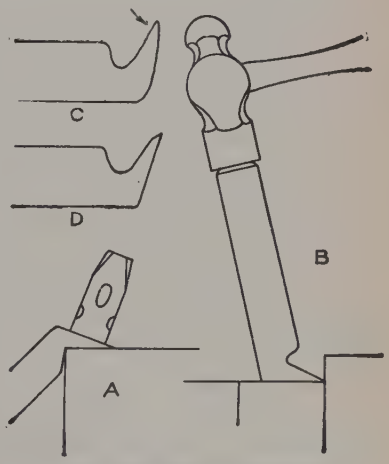


Fig. 138. Method of Shaping Finishing Tool

Flat Drill. Flat drills need no particular description as to forging and shaping. The size of the drill is determined by the width of the flat end, this being the same size as the hole the drill is intended to bore. If this dimension were 1 inch, the drill would be known as 1-inch drill. The drill should be made somewhat softer than lathe tools, the temper being drawn until a light brown shows at the cutting edge.

Springs. Springs are generally tempered in oil. The spring is heated to a uniform hardening heat and hardened by cooling in oil, usually lard or fish oil, as mineral oil is too uncertain in composition. The temper is drawn by holding the spring, still covered with oil, over the flame of the forge, and by heating until the oil burns over the entire spring. If the spring is not uniform in section throughout, it is generally advisable, while heating, to plunge it every few seconds into the oil bath, taking it out instantly and continuing the heating. This momentary plunge tends to equalize the heat by cooling the thinner parts.

The above method of tempering is known as blazing off, the

blazing point of the oil being used to indicate the temperature in place of the color of the scale. The same results could be obtained by polishing the spring and heating until it turned blue.

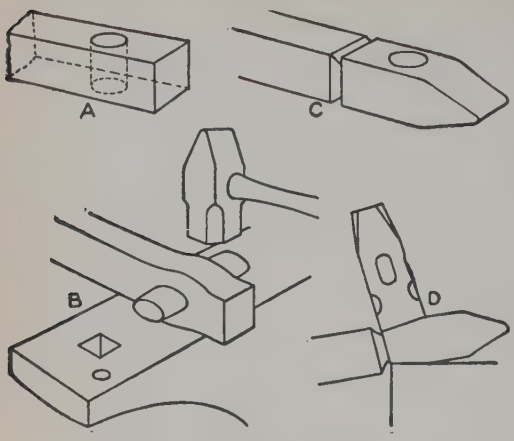


Fig. 139. Method of Making Hammer

Hammers. When making a hammer the stock should be taken large enough to make the largest part of the hammer without any upsetting. As a general rule the hammer is forged on the end of a bar and is finished as completely as possible before cutting off.

Riveting Hammer. About the easiest hammer to shape is the riveting hammer shown at *D*, Fig. 8. This hammer, as well as all other hammers, is started by first punching the hole for the eye as shown at *A*, Fig. 139. When the eye is punched the stock is generally bulged out sideways, and, in order to hold the shape of the eye while flattening down this bulge, a drift pin such as shown in Fig. 140 is used. This pin is made larger in the center and tapering at both ends. The center or larger part of the pin has the same shape as the finished eye of the hammer. This pin is driven into the punched hole and the sides of the eye forged into shape, as illustrated at *B*, Fig. 139. After the eye has been properly

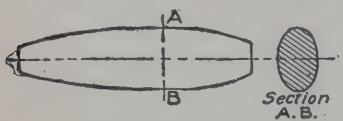


Fig. 140. Drift Pin

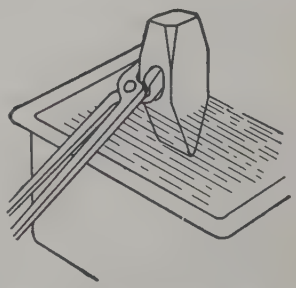


Fig. 141. Hardening Hammer Head

shaped, the next step is to shape down the tapering peen leaving the work, after a nick has been made around the bar where the face of the hammer will come, as shown at *C*. The end of the hammer toward the

face is then slightly tapered in the manner indicated at *D*. After the hammer has been as nearly as possible finished, it is cut from the bar and the face trued up. For tempering, the whole hammer is heated to an even hardening heat. The hammer is then grasped by placing one jaw of the tongs through the eye. Both ends are tempered, this being done by hardening first one end and then the other. The small end is first hardened by dipping in the water as shown at Fig. 141. As soon as this end is cooled the position of the hammer is instantly reversed and the face end hardened. While the large end is in the water the smaller end is polished and the temper color watched for. When a dark brown scale appears on the small end

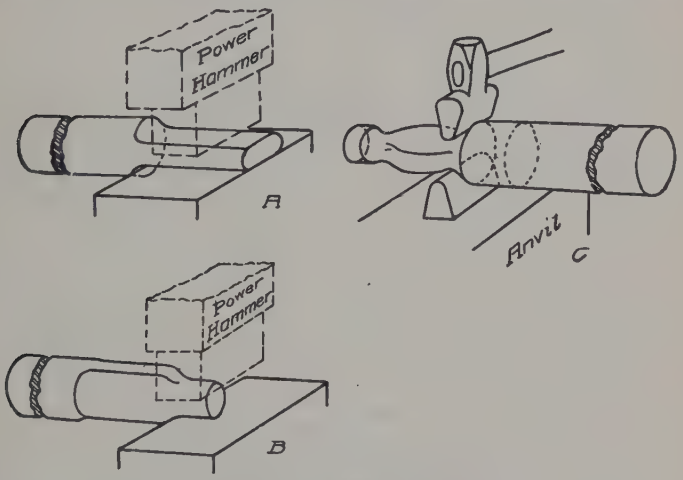


Fig. 142. Method of Making Ball-Peen Hammer

the hammer is again reversed bringing the large end uppermost and the peen in the water. The face end is then polished and the temper drawn. If the large end is properly hardened before the temper color appears on the small end, the hammer may be taken completely out of the water, the large end polished, and the colors watched for on both ends at once. As soon as one end shows the proper color it is promptly dipped in water, the other end following as soon as the color appears there; the eye should never be cooled while still red hot. For some work hammer faces should be left harder, but for ordinary use the temper as given above, is very satisfactory.

Ball-Peen Hammer. The general method of making a hammer of this kind is illustrated in Fig. 142. Starting with round stock

(carbon steel), flatten under a power hammer, if one is available, as at *A;* otherwise use a set hammer on an anvil in the same manner, and then work enough down for the ball peen, as shown at *B*. Then fullers are used as at *C*, to space off for the hole to be punched between the octagonal parts formed with the fullers. To keep from flattening the part through which the hole is punched, it should be placed on a bottom fuller of the proper size. Care should be taken not to heat the steel too hot for this operation, as heat cracks are sure to take place. The steel should be of fairly high carbon; not less than 1 per cent. Harden and temper to about dark straw color, or 430° Fahrenheit.

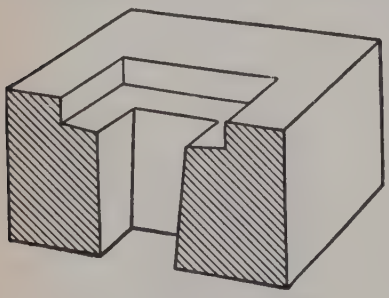


Fig. 143. Block for Upsetting

Blacksmith's Tools. Such tools—cold chisels, hot chisels, set hammers, and flatters—are made in much the same way as hammers. The wide face of the flatters may be upset by using a block such as is shown in Fig. 143. The heated end of the tool is dropped into the hole in the block and the face upset into the wide shallow opening. Swages may also be worked up in this way.

MISCELLANEOUS PROCESSES

Shrinking. When iron is heated it expands, and upon being cooled it contracts to about its original size. This property is utilized in doing what is known as shrinking. Fig. 144 shows a collar shrunk on a shaft. The collar and shaft are made separate, the hole through the collar being slightly less in diameter than the outside diameter of the shaft. The collar is then heated red hot and the heat causes the collar to expand, making the hole larger in diameter than the shaft. The collar, while still hot, is then placed on the shaft in proper position, and cooled as quickly as possible by pouring water on it. As

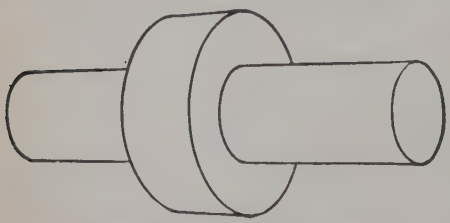


Fig. 144. Collar Shrunk on Shaft

TABLE IV*

Color Scale of Iron Heats

Color	Temperature (Degree Fahrenheit)
Red, lowest visible in dark	878
Red, lowest visible in daylight	887
Red, dull	1100
Red, full	1370
Red, light (scaling heat)	1550
Orange, full	1650
Orange, light	1725
Yellow, full	1825
Yellow, light	1950

the collar is cooled it contracts and squeezes, or locks, itself firmly in position. This principle of shrinking is used to a large extent where a firm, tight fit is wanted, the only objection being that it is rather difficult to take a piece off after it has once been shrunk into place.

Allowance for Shrinkage. In doing work in the blacksmith shop it must be constantly remembered that the work is larger when being worked than it is when cool. Allowance must, therefore, always be made for shrinkage. As the pattern-maker allows for the contraction of the molten metal to the cold casting, so the blacksmith must allow for the contraction of the hot iron or steel to the cold forging.

From the scale of iron heats at the several colors, given in Table IV, it will be seen that the temperature at which forgings are finished under the hammer, should be at about 900° Fahrenheit. When these same forgings are cold their temperature will be from 60° to 70° Fahrenheit. There is, therefore, a difference of at least 840° between the working and the finished temperature. The expansion of iron may be taken to average about .00000662 of its length for each increase of one degree Fahrenheit in its temperature. If a bar of machine steel exactly 2 feet long when cold is heated red hot and measured, it will be found to have increased nearly $\frac{1}{4}$ inch in length. Taking the temperature of the red heat as 1370° Fahrenheit, and that of the cold bar as 70° Fahrenheit, the increase in length would be $1300 \times .00000662 \times 24$ (length in inches) $= 0.206$ inches. This expansion must be allowed for when measuring forgings red hot.

*Table IV is based on temperatures given by Messrs. Taylor and White, Transactions American Society of Mechanical Engineers, Vol. XXI.

Brazing. When two pieces of iron or steel are welded together, they are joined by making the pieces so hot that the particles of one piece will stick to those of the other, no medium being used to join them. In brazing, however, the brass acts in joining two pieces of metal together in somewhat the same manner that glue does in joining two pieces of wood. Briefly the process is as follows: The surfaces to be joined are cleaned, held together by a suitable clamp, heated to the temperature of melting brass, flux added, and the brass melted into the joint. The brass used is generally in the shape of *spelter*, which is a finely granulated brass which melts at a comparatively low temperature. Spelter comes in several grades designated by hard, soft, etc., the harder spelters melting at higher heat but making a stronger joint. Brass wire or strips of rolled brass are sometimes used in place of spelter, brass wire in particular being very convenient

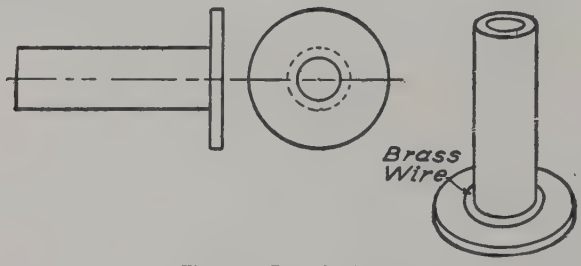


Fig. 145. Brazed Joints

in many places. A simple example of a brazed joint is shown in Fig. 145, where a flange is brazed to the end of a small pipe. It is not necessary in this case to use any clamps as the pieces will hold themselves together. The joint between the two should be made roughly. If a tight joint be used there will be no chance for the brass to run in. The joint should fit in spots but not all around. Before putting the two pieces together, the surfaces to be joined should be cleaned free from loose dirt and scale. When ready for brazing the joint is smeared with a *flux* (1 part sal ammoniac, 6 or 8 parts borax) which may be added dry or put on in the form of a paste mixed with water. The joint is then heated and the spelter mixed with flux sprinkled on and melted into place. Brass wire could be used in place of the spelter in the manner indicated, the wire being bent into a ring and laid round the joint as shown. Ordinary borax may be used as a flux, although not as good as the mixture used above. The heat

should be gradually raised until the brass melts and runs all around and into the joint, when the piece should be lifted from the fire and thoroughly cleaned by scraping off the melted borax and scale. It is necessary to remove the borax, as it leaves a hard glassy scale which is particularly disagreeable if any filing or finishing has to be done to the joint. This scale may be loosened by plunging the work while still red hot into cold water. Almost any metal that will stand the heat, may be brazed. Great care must be used in brazing cast iron to have the surfaces in contact properly cleaned to start with, and then properly protected from the oxidizing influences of the air and fire while being heated.

Bending Cast Iron. It is sometimes necessary to straighten a casting which has become warped or twisted. Cast iron may be twisted or bent to quite an extent if worked cautiously. The bending may generally be done at about the ordinary hardening heat of tool steel and should be done by a steadily applied pressure, not by blows. There is more danger of breaking the work by working it at too high a heat than by working at too low. As an example of how iron may be twisted, a bar of gray cast iron 1 inch square and a foot long may be twisted through about 90 degrees before it will break.

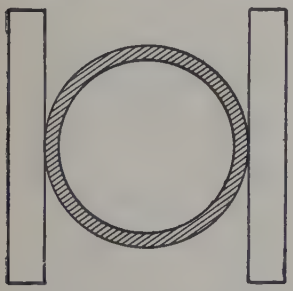


Fig. 146. Method of Bending Pipe

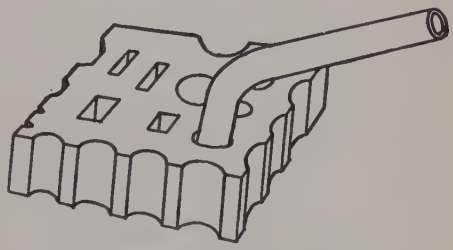


Fig. 147. Bending Pipe on Swage Block

Pipe Bending. A piece of pipe when bent always has a tendency to collapse, and, if this collapsing can be prevented by keeping the sides of the pipe from spreading, a pipe may be successfully bent into almost any shape. One way of doing this would be to bend the pipe between two flat plates as shown in Fig. 146, the plates being the same distance apart as the outside diameter of the pipe. In bending large pipe, the sides are sometimes prevented from bulging by working in with a flatter. Where a single piece is to be bent, it may be

done by heating the pipe and inserting one end in one of the holes in a swage block as shown in Fig. 147, the pipe being then bent by bearing down on the free end. As soon as a slight bend is made it is generally necessary to lay the pipe flat on the anvil and work down the bulge with a flatter. Where many pieces are to be bent, a grooved jig such as shown in Fig. 148 is sometimes used. The jig is of such a shape that the pipe is completely surrounded where it is being bent, thus not having any opportunity to collapse or bulge. Pipe is sometimes filled full of sand for bending. This helps to some extent. Care must be taken to see that the pipe is full and that the ends are solidly plugged. For bending thin copper tubing, it may be filled with melted rosin. This gives very satisfactory results for this character of work. After bending, the rosin is removed by simply heating the pipe.

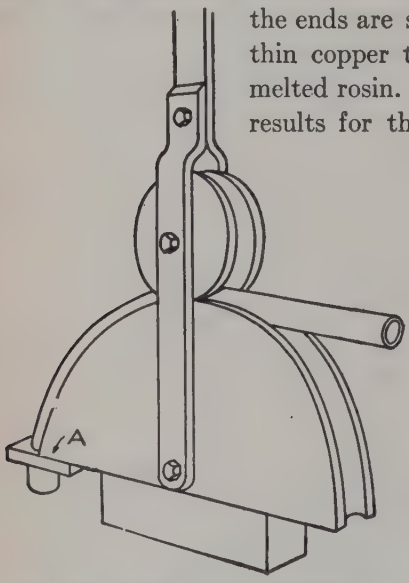


Fig. 148. Bending Pipe in Grooved Jig

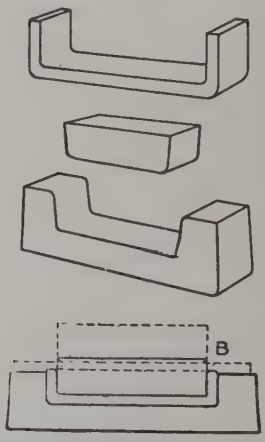


Fig. 149. Block for Simple Bend

Duplicate Work. Where several pieces are to be exactly alike in a shop that is not equipped for special work, it is sometimes practical to use a jig for performing the operations. For simple bending the jig may consist of a set of cast-iron blocks. Fig. 149 illustrates a simple bend with the block used for doing the work. The work is done as shown at *B*. The piece to be bent is placed, as shown by the dotted lines, with the bending block on top. The bending is done by one or two strokes of the steam hammer. For convenience in handling, the bending blocks are sometimes held by a spring

handle as shown in Fig. 150. The blocks in this case are for bending the hooks shown at *A*. The handle is simply a piece of ½ inch round iron with the ends screwed into the cast-iron blocks and held firmly by the lock nuts shown. This makes a cheap arrangement for

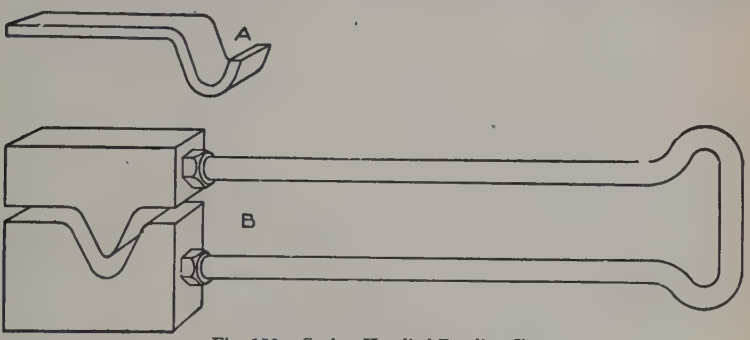


Fig. 150. Spring-Handled Bending Jig

a variety of work, as the same handles may be used on various sets of blocks. Where a great number of pieces are to be made, these blocks or bending dies may be made of such a shape that they can be keyed on the steam hammer in place of the regular flat dies.

Die Forging. Pieces are sometimes shaped between formed steel dies where many are to be made exactly alike. An example of this sort of work is the eye bolt, Fig. 151. Round stock is used and is first shaped like *A*, Fig. 152. The shaping is done in the dies shown at *B*, which are simply two small blocks of tool steel fastened together with a spring handle, the inside faces of the blocks being formed to shape the piece as shown. The end of the bar is heated, placed between the die blocks and hammered until it takes the required shape, being turned through about 90 degrees between each two blows of the steam hammer, and the hammering continued until the die faces just touch. For the second step the ball is flattened to about the thickness of the finished eye and the hole punched under the steam hammer with an ordinary punch, leaving the work as shown at *C*. The final shaping is done with the finishing die *D*. This die is so shaped that when the two parts are together, the hole left is exactly the shape of the finished forging. In the first die it

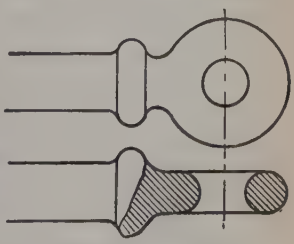


Fig. 151. Eye Bolt

will be noticed that the holes do not conform exactly to the desired shape of the forging, being, instead of semicircular, considerably rounded off at the edges. This is shown more clearly in Fig. 153

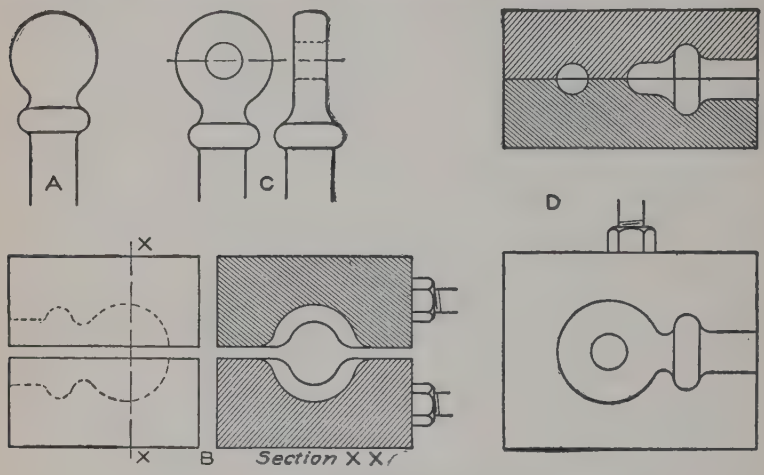


Fig. 152. Shaping Eye Bolt in Dies

at *A*, where the dotted lines show the shape of the forging, the solid lines the shape of the die. The object of the above is this: If the hole is semicircular in section, the stock, being larger than the smaller parts of the hole, after a blow will be left like *B*, the metal being forced out between the flat faces of the die and forming fins. When the bar is turned these fins are worked back and make a *cold-shut*. When the hole is a modified semicircle the stock will be formed like *C*, and may be turned and worked without danger of cold-shuts. Dies for this kind of work are sometimes made of cast iron. When made of tool steel it is sometimes possible to shape them hot. A master forging is first made of tool steel to exactly the shape of the required forging. The blocks for the dies are then forged with flat faces. These blocks are fastened to the handle and then heated red hot. The master forging is then placed between them and the dies hammered down over the forging, leaving the cavity just the proper shape.

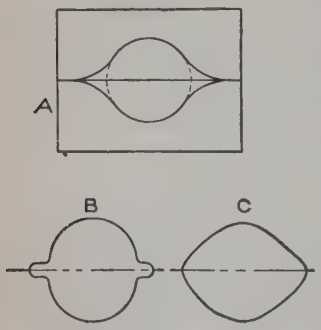


Fig. 153. Shapes of Forging and Die

HEAVY FORGING

Steam Hammer. An ordinary form of steam hammer is shown in Fig. 154. Its essential parts are an inverted steam cylinder, to whose piston rod the hammer head is attached, and the frame for carrying the whole. The hammer is raised by admitting steam beneath the piston. The blow is dealt by exhausting the steam from beneath the piston and admitting above. The head is thus accelerated by gravity and by the pressure of steam above the piston. The valve gear is so arranged that the intensity of the blow may be varied by changing the amount of steam admitted to the piston on its downward stroke. The steam admitted below on the same stroke forms a cushion for the absorption of the momentum of the head. In this way the lightest of taps and the heaviest of blows can be delivered by the same hammer. These hammers are also made in a great variety of sizes. Steam hammers are rated by the weight of the falling parts, i.e., the piston rod, ram or head, and hammer die. A hammer in which these parts weigh 400 pounds would be called a 400-pound hammer. Steam hammers are made in two distinct parts: the frame, carrying the hammer or ram, and the anvil, on which the hammer strikes. The frame is carried on a heavy foundation, and the heavy anvil, which is generally made of cast iron and fitted with a die block of tool steel, rests upon a heavier foundation of timber or masonry capped with a timber. The object of these separate foundations is to allow the anvil to give slightly under a blow without disturbing the frame. On very light power hammers the anvil and frame are sometimes made together.

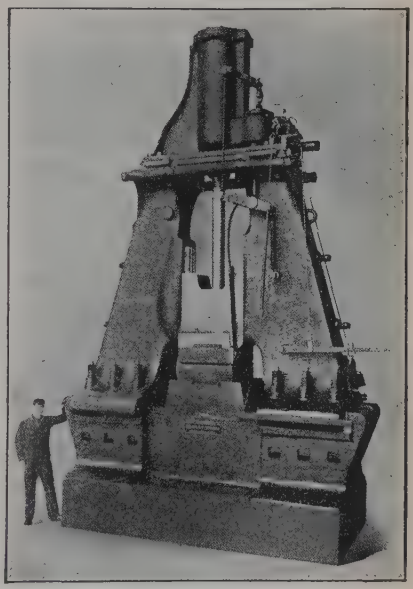


Fig. 154. Typical Steam Hammer
Courtesy of Niles-Bement-Pond Company.

Hammer Dies. The dies, as most commonly used with a steam hammer, have flat faces. The best ones are made of tool steel. These

dies may be made of tool steel and left unhardened, then when the dies become battered out of shape from use, they may be trued up and refaced without going to the trouble of annealing and hardening. Dies of gray cast iron and cast iron with a chilled face are also quite

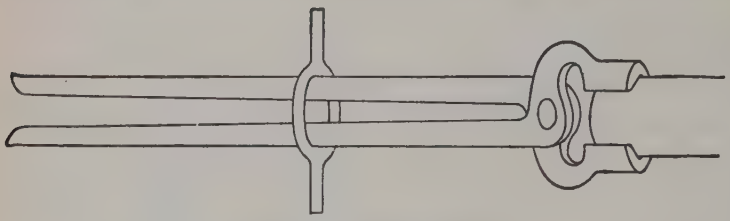


Fig. 155. Tongs for Heavy Work

commonly used. Ordinary gray cast iron is used, particularly when special shaped dies are employed for welding and light bending.

Tongs. Tongs for steam-hammer work should always be fitted carefully, and should grip the stock firmly on at least three sides. A quite common shape for tongs for heavy work is shown in Fig. 155. To hold the tongs securely on the work and to make it easier to handle them, a link is sometimes used of the shape shown. This is driven firmly over the handles of the tongs and the projecting ends are used as handles for turning the work.

Hammer Chisels. The common shape for hot chisels for use under the steam hammer is given in Fig. 156. The handle and blade

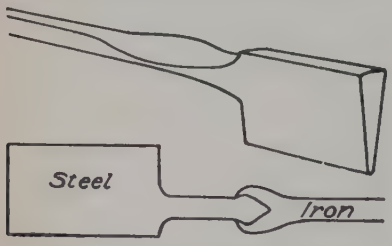


Fig. 156. Steam Hammer Chisels

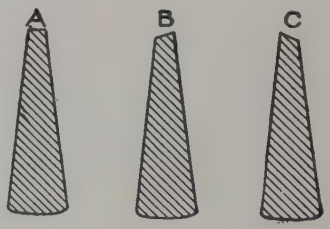


Fig. 157. Sections of Chisel Blades

are sometimes made from one piece of tool steel. Sometimes the blade is made of tool steel and an iron handle welded on as shown in the sketch. The handle next to the blade should be flattened out to form sort of a spring which permits a little give when using the chisel. The edge of the chisel should be left square across and not rounding. The proper shape is shown at *A*, Fig. 157. Sometimes

for special work the edge may be slightly beveled as at *B* or *C*. For cutting or nicking bars cold, a chisel similar in shape to Fig. 158 is sometimes used. This is made very flat and stumpy to resist the crushing effect of heavy blows. For cutting into corners a chisel

Fig. 158. Chisel for Cutting Cold Bars

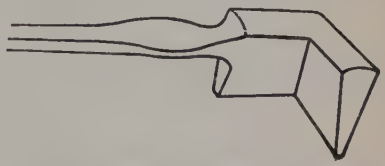


Fig. 159. Chisel for Cutting Into Corners

similar in shape to Fig. 159 is sometimes used. For bent or irregular work the chisel may be formed accordingly. For cutting off hot stock the method used is about as illustrated in Fig. 160, i.e., the work is cut nearly through as shown at *A*. The bar is then turned over and a thin strip of steel with square corners placed on top as shown at *B*. A quick heavy blow of the hammer drives this steel bar through the work and carries away the thin fin shown, leaving both of the cut ends clean and smooth.

Fig. 160. Method of Cutting Off Hot Stock

Tools. *Swages.* The tools used for steam-hammer work are generally very simple. Swages for finishing work up to 3 or 4 inches in diameter are commonly made in the shape shown in Fig. 161. The handle is made in the shape of a spring and may be either made in one piece with the blocks and drawn out as shown at *C*, or may be inserted as shown at *B*. This sort of tool is known as a *spring tool*. Another sort of swage sometimes used is illustrated in Fig. 162, the top swage at *A*, the bottom swage at *B*. This sort of swage is used on a die block which has a square hole cut in its face similar to the hardie hole in an anvil. The short

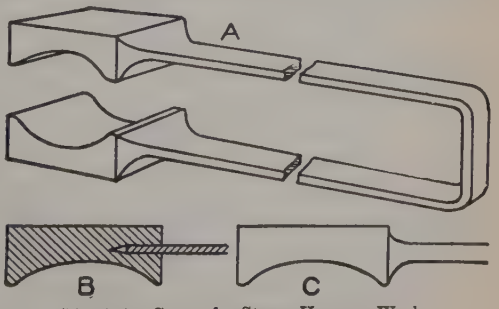


Fig. 161. Swage for Steam-Hammer Work

horn X, of the swage, fits into this hole, the other two projections coming over the side of the anvil block.

Tapering and Fullering Tool. The faces of the anvil and hammer dies are flat and parallel, and it is, of course, impossible to finish tapering work smooth between the bare dies. This work may be done by using a tool similar to Fig. 163. Its method of use is shown in Fig. 164, the roughing being done with the round side down and the finishing with the flat side. Fullers used for ordinary hand forgings are seldom employed in steam-hammer work. Round bars are used in their place in the manner illustrated in Fig. 165. If a nick is wanted on one side only, simply one round bar is used. Care must always be taken to be sure that the work is in the proper position before striking a heavy blow with the hammer. To do this the hammer should be brought down lightly on the work thus bringing the piece to a flat bearing for the first blow.

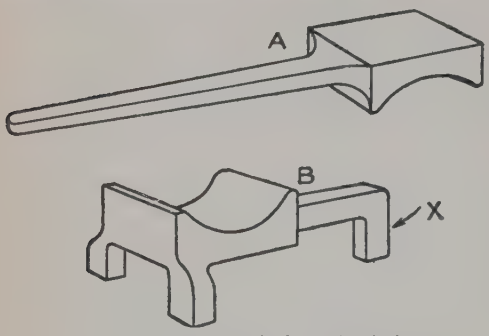


Fig. 162. Swage Used on Die Block

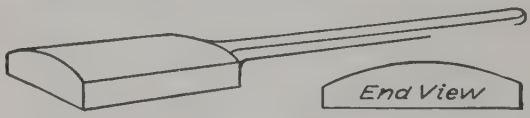


Fig. 163. Tapering and Fullering Tool

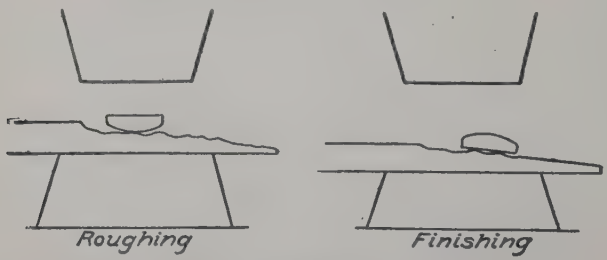


Fig. 164. Method of Using Tapering and Fullering Tool

Squaring up Work. It frequently happens that work is knocked lopsided under the hammer, being worked up into some such shape as shown at A, Fig. 166. To correct this and bring the work up

square, the bar should be put under the hammer and there knocked into shape *B*, then rolled in the direction indicated by the arrow until shaped as at *C*, when it may be worked down square and finished like *D*.

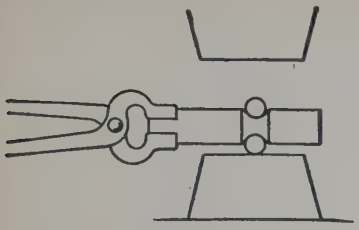


Fig. 165. Round Bars for Hand Forging

Examples of Work. *Crank Shaft.* The crank shaft shown in Figs. 91 and

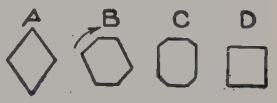


Fig. 166. Squaring Up Work

92 is quite a common example of steam-hammer work. The stock is first worked as illustrated in Fig. 167, the cuts being on each side of the crank cheek, and a special tool being used for this as illustrated. When the cuts are very deep, they should first be made with a hot chisel and then opened up with this spreading tool. With light cuts, however, both operations may be done with a spreading tool at the same time. Care must be taken when flattening out the ends, to prevent any of the material from doubling over and forming a cold-shut. After the ends are hammered out, the corners next to the cheeks may be squared by using a block as shown in Fig. 93.

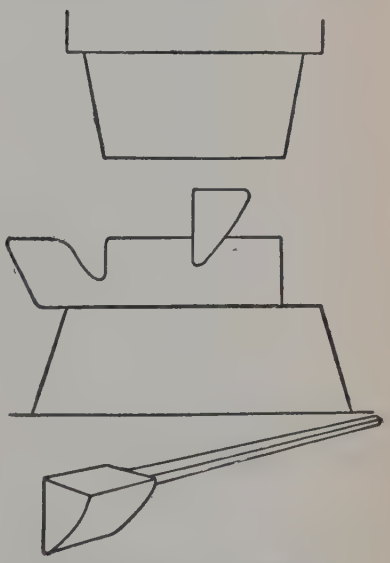


Fig. 167. Diagram Illustrating Steam-Hammer Work on Crank Shaft

Connecting Rod. The forging illustrated in Fig. 89, while hardly the exact proportions of the connecting rod, is near enough the proper shape to give a good example of this kind of forging. The work is first started by making two cuts as illustrated in Fig. 168. The metal between the two cuts is then drawn out by using two steel blocks, Fig. 169, until it is stretched long enough for the corners of the blocks to clear the hammer dies; then the work is done directly upon the bare die.

DROP FORGING

Development. Drop forgings were made first about 60 years ago, and from the necessarily crude methods which were first employed, the art of forging has developed into one of the largest branches of the mechanical arts. Great advancement has been made within the last few years, so that its scope of usefulness, as well as possibilities, are practically unlimited. This progress has been made possible by scientific investigations, improved machinery

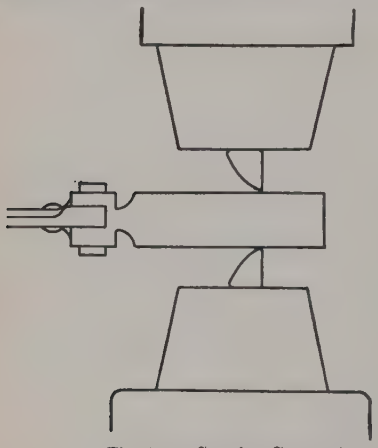


Fig. 168. Starting Connecting Rod Forging

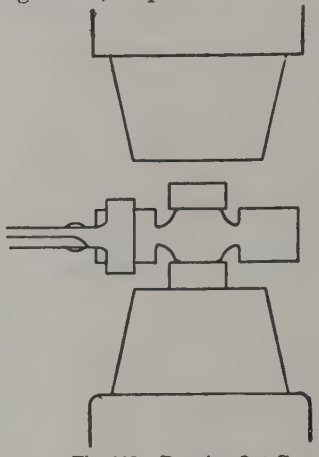


Fig. 169. Drawing Out Connecting Rod

and die materials, and especially by the exhaustive study of steel and its treatment.

The early history of drop forging shows that more or less depended on the skill of the blacksmith. He was obliged to work out the material by hand almost to the desired shape, then, with the aid of portable tools which were used in conjunction with the power and the steam hammer, the forgings were finished to uniform size. Corresponding to the development of machinery along other lines, however, it was only natural that the same progress should affect the forging business.

The sewing-machine, shoe-machine, harvester-machine, and automobile industries have been more instrumental than any other agencies in bringing stamp or drop forging to its present simplicity. From the fact that drop forging is purely mechanical, the word simplicity clearly signifies the methods used, which effect a wonderful reduction in the cost of production.

Forgings can be made in greater variety, and those that are most difficult or even impossible to finish over the anvil are made with apparent ease under the drop hammer. There seems to be no

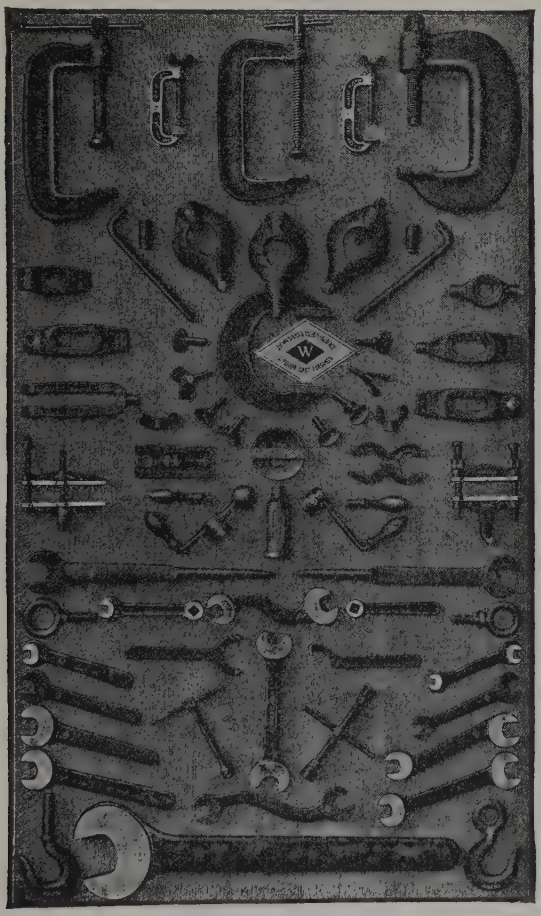


Fig. 170. Typical Drop Forge Tools
Courtesy of J. H. Williams and Company, Brooklyn, New York

limit to design, and the best feature of all is that the work is done more accurately, imparting a finish to every detail.

From the fact that to a great extent drop forgings have replaced malleable-iron castings, there is no doubt that new fields have opened to create a demand for forgings greater than would have developed if the mechanical world had been obliged to depend on the former methods of hand forging.

Process. Drop forgings are made by the use of dies. These dies are made in two parts and into them are sunk exact impressions of the parts wanted. One-half of the die is securely attached to the base of the hammer, the upper part being fastened to the ram which travels vertically between two guides. By continually raising and dropping this ram, the heated metal which is held between the two parts of the die is forced into the impressions cut into the dies. In forcing the metal into the die, there is a small amount called the *flash*, which overflows the impression. This flash is removed by a heavy turning press to which are attached dies cut to the correct size and shape to finish the forging.

In the process of forging, a thin scale is formed on the forging proper. This scale has to be removed in order that the finished

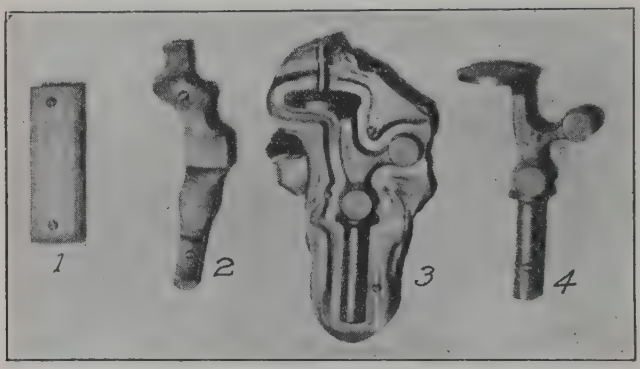


Fig. 171. Steps in Forging Automobile Part

forging may be clean and smooth, and this is accomplished by a pickling process or by sand blasting. The pickling process consists of dipping each forging in a strong solution of acid which eats off all the scale.

Drop Hammer. To meet the requirements of an up-to-date forge shop, either of the types shown in Figs. 19 or 133 are suitable. They are almost indestructible machines, the capacity of which seems to be limited only by the ingenuity of the die sinker. The bases are of cast iron and in one piece, a weight ration of 15:1 between base and hammer being adopted. If the hammer weighs 2,000 pounds the base would weigh 30,000 pounds.

Specimens of Drop Forging. The light work illustrated in Fig. 170 is a group of drop-forged tools made by J. H. Williams and

Company, Brooklyn, New York, and shows some of the possibilities of drop forging.

Referring to Fig. 171, *1* is a portion of steel bar from which 1½-inch lathe dogs are forged in a 1,000-pound drop hammer; *2* is the material after sizing in an edger and being cut out on the side, also showing the tang or sprue by which the operator holds the piece—3 blows of the hammer are required at this stage; *3* is the forging after the material has been further spread or "broken down" in the blanking or the roughing impression of the die—6 blows of the hammer are required here; *4* is the dog fully forged and with tail bent in the same operation, showing the fin or flash thrown out between the dies while forging—6 to 7 blows of the hammer are required.

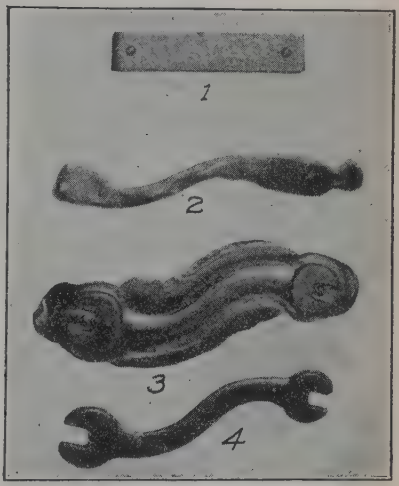


Fig. 172. Steps in Forging S-Wrench

In Fig. 172 are shown the different steps for making an S-wrench in four operations, from stock 1⅛ inch wide and ½ inch thick, as at *1; 2* shows the roughing-die work; *3* shows the forging hammered down with flash not removed; *4* shows the forging finished and the flash trimmed off.

HEAT TREATMENT

Relation to Steel Development. The development of high-speed and of high-grade carbon steel has resulted in the development of scientific heat treatment. Where the process is applied, those cases in which operations are conducted in an accurate and intelligent manner apparently are in by far the smaller proportion. There seems to be less attention paid to heat treatment than to the composition of the steel; but the heat treatment is far more important than a small variation in the chemical composition of the steel.

Proper Treatment Important. The physical changes which take place when a piece of steel is heated and quenched or slowly cooled

are controlled by definite laws, and, with steels containing a high per cent of carbon with other alloying elements, the operation of heat-treating is a very delicate one, such that a slight variation even with the best of steel would give very poor results.

The proper or most practical heat treatments for the various steels have been determined by their manufacturers before placing them on the market, and the directions given should be carried out. To make one heat treatment which is satisfactory for all steels is impossible, so the manufacturers' recommendations should be followed.

Factors in Heat Treatment. Before going into the details of heat treatment, it is necessary to know some of the properties which enter into the steel, so as to understand the treatment more fully.

Steel, as we obtain it from the market at the present time, is a combination of iron and carbon and some impurities such as sulphur and phosphorus, though to produce particular results, these latter sometimes are added together with many other elements such as manganese, silicon, nickel, chromium, tungsten, molybdenum, vanadium, etc., either accidentally or purposely included for their effects.

Carbon Principal Determining Element. The principal element determining the properties of crucible tool steel is carbon. Pure iron is very nearly as soft as copper, while, with an increasing amount of carbon, steel becomes harder and stronger, but less ductile, until a carbon content of about 0.90 per cent is reached. Steel of this carbon content is the one mostly used for common machine-shop tools. Above this point other additions of carbon result in not only increasing hardness but also increasing brittleness.

Steels most generally useful in the hardened state have carbon from 0.90 per cent to 1.20 per cent, between which points the hardness is sufficient for almost every purpose. Steel containing carbon up to about 0.15 per cent carbon generally is called *ingot iron;* that from 0.15 per cent to 0.35 per cent is *machinery steel;* that from 0.35 per cent to 0.60 per cent is *crucible machinery steel;* and that from 0.60 per cent up is *tool steel.* Steels containing only carbon with small quantities of silicon, manganese, and the always present sulphur and phosphorus, generally are called *straight carbon steels.* Those owing their peculiar properties to some ingredients other than carbon are called *alloy steels.*

Critical Temperature in Hardening. For every grade of steel there is a so-called *critical temperature* or point of transformation. This temperature varies according to the various compositions and the carbon content of the steels. The phenomenon probably is more marked in the alloy steels than in straight carbon steels. On heating through the critical temperature or critical range the steel takes on hardness when cooled quickly, the hardness being according to its carbon content and the quickness of cooling.

When working a new steel for the first time, a blacksmith should acquaint himself with the particular hardening temperature of the material, and in practice he should be very sure not to vary or exceed it much.

Variation of Structure. To harden, steel must be heated to, or a little above, this critical temperature and be cooled suddenly, the percentage of hardness which the steel is capable of assuming being proportional to the speed of cooling—the quicker the cooling, the harder the steel. If heated below the critical temperature, even though quenched, steel does not take on hardness, but remains soft or partly annealed. On heating through the critical temperature, the previously existing structure is obliterated or tends to become obliterated, and up to this temperature, or just above it, is when steel possesses the finest structure which it is capable of assuming. The rate of obliteration of the old structure in a piece of steel depends upon the temperature reached and upon the time the steel is maintained at that temperature, the change proceeding more rapidly with increase of temperature. So, with the obliteration of the old structure, a new structure begins to grow, and its size increases with time and temperature, but more rapidly with increase of temperature than with increase of time at a lower temperature.

Once heated above the critical point and having reached the heat of hardening, steel may be cooled slowly to a certain degree and not lose its power of hardening if cooled suddenly. But to so let steel cool is very bad practice, because, during slow cooling, the micro-constituents of the steel tend to separate, as the coarser appearance shows on breaking the steel for the purpose of examining the grain. Below the critical temperature, slowness of cooling has no effect on the size of grain, but leaves the steel soft.

A bad practice sometimes followed by users of steel is to break

off a bar of steel as it comes from the storehouse, examine the fracture, and if the steel shows a coarse grain, to condemn the steel. The appearance of the grain in the steel depends on its heat when it left the hammer or the rolling mill; if the heat were high, it would show a coarse grain; if the heat were low, it would show a closer fine grain. If the steel is heated to the proper hardening point afterward, the grain is the same, and there is no difference in its physical properties.

PROCESSES OF TREATING

Different Purposes. Steel is heated for four distinct purposes: (1) forging; (2) annealing; (3) hardening; and (4) tempering.

HEATING FOR FORGING

Uniform Heating Essential. In the first place, when steel is to be heated in a blacksmith forge, a clean deep fire is necessary for uniform results. If the fire is shallow, the steel oxidizes. The trouble in a forge fire usually is uneven heat, either too low or too high. Uneven heating causes strains from which trouble may result afterward in the form of fire cracks when tools are being hardened. It is essential that a piece of steel to be forged should be heated uniformly throughout its section, because if it is hot on the surface, and the interior is not yet up to heat, working it may break the center transversely, while if it is hot in the center and cold on the surface, generally the small surface cracks. Heat should be raised slowly and uniformly and should not be higher than is necessary for the work required. If through carelessness the heat rises too high, the temperature of the steel should be allowed to drop below the critical point and then should be raised to the proper point to avoid cracking the steel.

Trouble with Quick Heating. Suppose the piece to be forged has been put in a very hot fire and forced as quickly as possible to high yellow heat. If so treated, the outside will be soft and in good condition for forging, while the center parts will be not more than red hot. The highly heated soft outside will have very little tenacity, that is to say, this part will be so far advanced toward fusion that the particles will slide easily over one another, while the inside parts will be hard and possessed of high tenacity, and the particles will not slide so easily over one another.

Let the piece be placed under a hammer and forged, and the result is as shown in Fig. 173. The soft outside yields so much more readily than the hard inside that the outer part is full of small cracks, while the inside remains sound, and the piece is pronounced *burned.*

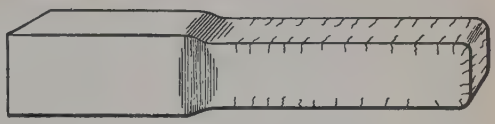


Fig. 173. Effect on Stock if Forged When Outside Is Too Hot

Exterior Too Cool. Suppose the case to be reversed, and the inside to be much hotter than the outside—that is, the inside to be heated to white heat, while the outside is hard and firm. Now, when the piece is forged, the conditions shown in Fig. 174 result. The outside is sound and the whole piece appears perfectly good until finished and cooled off and then it is found to be a little hollow inside, and is branded *burst.*

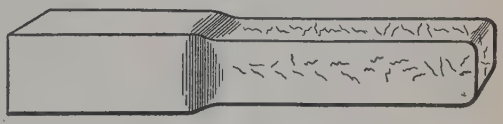


Fig. 174. Effect on Stock if Forged When Outside Is Too Cool

In either case, if the piece had been heated soft all through, or if it had been heated only to red heat all through, it could have been forged perfectly sound.

Proper Forging Heat. Steel should be forged quickly with as few heats as possible, and should not be worked or finished when too cold. More steel is injured by hammering when too cold than when it is overheated; the usual excuse given for the former procedure being that it refines the grain—so it does, but it should be remembered that when steel has to be heated for subsequent hardening the effect of all the previous refining is obliterated.

If it is questioned then why there is ever any necessity for a smith to use a low heat in forging when high heat will do as well, it may be answered that in some cases a high heat may be more desirable to save labor, but that, in every case where a fine steel is to be used for cutting purposes, it must be borne in mind that too high a heat is apt to cause surface cracks; at the same time too low a heat and light hammer blows also will produce surface cracks.

Steel never should be allowed to soak too long in either a forge fire or a furnace after it has come up to a desired temperature, this having a tendency to decarbonize the steel and to make it coarse

and brittle. Soaking does steel more injury than any bad practice known to the most experienced.

Simple Test of Heat Effect. A very simple method by which any worker in steel should be able to obtain a satisfactory test for the effect of heat upon steel is to take a bar of steel of ordinary size, say about 1 inch by $\frac{1}{2}$ inch, heat 6 or 8 inches of one end to a low red heat, and nick the heated part all around the bar at intervals of $\frac{1}{2}$ to $\frac{3}{4}$ of an inch, until eight or nine notches are cut. Next place the end of the bar in a very hot fire and heat it white hot until it nearly melts at the extreme end, leaving the other parts enough out of the fire so that they are heated by conduction. Let the end remain in the fire until the last piece nicked is not quite red hot, and the next to the last barely red hot. Now, if the pieces are numbered from 1 to 8, commencing at the outer end, No. 1 is white hot, No. 2 is yellowish white, No. 3 is high yellow, No. 4 is yellow or orange hot, No. 5 is high red hot, No. 6 is red hot, No. 7 is low red hot, and No. 8 is black. As soon as heated, let the bar be quenched in cold water and kept there until quite cold.

After cooling, the bar should be wiped dry carefully, especially on the notches. An examination by the file reveals the following, if high-carbon steel has been used: piece No. 1 scratches glass; Nos. 2, 3, and 4 are excessively hard; Nos. 5 and 6 are well hardened; No. 7 is about hard enough for tap steel; No. 8 is not hardened. Now break off the pieces over the corner of the anvil—they should be caught in a clean keg or box to keep the fracture clean and bright; No. 1 is found to be as brittle as glass with a coarse yellowish and very lustrous grain; No. 2 is found to be nearly as brittle and not quite so coarse or yellow; and so on, until Nos. 6 and 7 are reached—these are very strong with a finer grain; No. 8 is unhardened and shows the original grain of the bar.

ANNEALING

General Process. Steel is annealed for two distinct reasons: (1) to soften the metal for machining; and (2) to relieve the strains in the steel caused by hammering or by bending in the mill or the forge shop.

The process is heating, and then slow cooling. The steel should be heated a little above its critical temperature; for if heated below

this temperature, all strain in the steel is not released and warping takes place when the hardening heat is reached.

As is noted under "Hardening", the rapidity of cooling determines the final hardness of the steel and if the steel is cooled very slowly it will be left very soft; while if cooled rapidly, it will be left hard. This difference in the cooling time is the only difference between its hardening and its annealing. Both should be done from the same heat.

Annealing High-Speed Steel. For good results in annealing high-speed steels, the following rules must be observed:

(1) Heat should be as near to 1500 degrees as possible. If the heat reached were only 1250 degrees, the steel would retain its original hardness. If heated to 1700 or 1800 degrees, the steel would be soft but would show brittleness with a coarse grain. If there were a further increase in heat, the steel would become hard and unannealed, and the fracture from this temperature would be dull and lifeless and would show a marked decarbonization.

(2) The steel should be packed in boxes or pipes, in powdered charcoal or lime, and sealed with fire clay, and in packing it should be seen that no part of the steel comes in contact with the box or pipes. If the parts come together, that does no harm.

(3) The heating should be started slowly and there should be given plenty of time for cooling. If a forge fire is used for annealing, leave the box in the fire and let it remain until cold, or if the forge fire has to be used for other purposes, the box can be put in some place out of the way and then covered with ashes, lime, or better still, charcoal. In all cases a slow cooling is necessary. If a furnace is used, heat slowly to full red or about 1500° Fahrenheit. Hold the heat long enough to be sure of penetration through the box and the steel to be annealed, and then shut off the heat and let the steel cool off with the furnace.

Water Method. Another method is water annealing. If only a few pieces are to be annealed for quick use, heat the steel to between 750° and 800° Fahrenheit, plunge it into water which has been heated to about 150° or 160° Fahrenheit, and allow it to remain until it becomes the same temperature as the bath. The heating should be slow and uniform for good results. To heat rapidly will cause internal strains and is apt to increase the risk of rupture when the steel is plunged into the water.

This last method is not to be recommended as it is not effective on all high-speed steels.

Annealing Copper and Brass. The treatment of these two metals consists in heating them to a red heat and then cooling suddenly in cold water. When copper or brass is hammered to any extent, it becomes hard and springy, and, if it has to be further worked, it must be annealed or softened, otherwise it is almost sure to split.

HARDENING

Purpose. Hardening generally is understood to mean the heating of a piece of steel to a certain temperature and plunging it into a bath of some kind for the purpose of cooling it. While this definition holds good for most steels, a few alloy steels now on the market reverse this method; steels known as air-hardened or self-hardening obtain their hardest and toughest state by a slow cooling process rather than by a sudden one.

Two reasons may be mentioned for the desirability of hardening steel: (1) to give the steel a cutting edge such as is required for all cutting tools; and (2) to alter the static strength and dynamic qualities of the metal so it will give the best results for the moving parts of machinery.

Essential Features. To harden steel, therefore, it is requisite that the heating produce a change in the structure, and that the quenching which follows the heating retain the whole or a part of the elements produced by this change. It is therefore necessary, as in annealing, that the temperature of the steel be raised to a point slightly above the point of transformation.

Point of Transformation. As the point of transformation varies with the different ingredients which are alloyed with steel, it is necessary to find out where this point is in the steel to be hardened. A steel may be heated to 1300° Fahrenheit, which is above the point of transformation in some steels, and no change in structure may occur; therefore no result in hardness is obtained. If this same piece is heated to 1450° Fahrenheit, which may be considered the point of transformation in this piece, the intermolecular transformation which consists of the passage of the carbon from the combined into the dissolved state takes place, and the steel assumes the hardest state possible, if properly cooled.

Influencing Factors. Thus the factors which have an influence on the results of hardening are: (1) the nature and composition of the metal; (2) the temperature of the metal when quenched; and (3) the nature, volume, and temperature of the quenching bath.

Carbon Content. The constitution of a given steel is not the same in the hardened as in the normal condition, owing to the carbon not being similarly disposed. In the annealed or normal steel it is in the free state, while in a hardened steel it is in a state of solution which we may call martensite, and this contains more or less carbon according to the original carbon content of the steel. The composition, and therefore the mechanical properties, depend principally upon the carbon content, the mechanical properties being changed slowly and gradually by the increase in carbon.

In regard to mechanical properties, the higher the temperature above the critical point, the lower the tensile strength, and the less the elongation, which means that the steel becomes more brittle with each increase in temperature. Coarsening of the grain, reduction of the tensile strength, and elongation lead to the conclusion that in practice 40° Fahrenheit above the highest point of transformation is the extreme limit to which steel should be raised to obtain the best results in hardening. The same figures hold also for annealing.

Results. The results obtained in hardening steel are: increase of tensile strength and of elastic limit, and reduction of elongation —the effect being greater in proportion to the carbon content; and due to quenching at the proper temperature, greater homogeneity, which aids resistance to shock.

Preparatory Heating. The most important feature to be taken into consideration is the method of heating, which should be such that the tool may be brought slowly and evenly to the hardening point without coming into contact with air or any form of gas which would oxidize the steel. Great care should be used, first, to protect the cutting edges and working parts from heating more rapidly than the bodies of the pieces; next, that the whole part to be hardened be heated through uniformly without any part being visibly hotter than another. A good oil or gas muffle furnace, provided care is taken to assure proper combustion, makes the best heating medium. For small tools, etc., a lead bath is very good.

Liquid Baths. The liquid baths commonly used for heating steel preparatory to hardening are molten lead, cyanide of potassium, barium chloride, a mixture of barium and potassium chlorides and other metallic salts.

Anyone using any of these different baths cannot be too careful in preventing an accident. If there is ever so little moisture of any kind on the tool to be immersed, it causes the molten liquid to fly in all directions. Before putting any tool into the bath, be sure that it is perfectly dry. The safe method is to pre-heat all tools before immersing them.

Lead at any heat above 1200° Fahrenheit gives off a slight vapor which is poisonous. Cyanide of potassium should be carefully used, as it is a virulent poison. The furnaces for heating these liquid baths should be equipped with hoods to carry away the fumes. It is a very good idea to put powdered charcoal on top of the molten liquid as charcoal acts as a purifier.

Hardening Bath. As it is necessary to maintain the steel in the state it was at the moment quenching began, the quenching bath is a very important part of the process of hardening. The better the bath, the more nearly perfection is attained.

Various baths are used for cooling steel when hardening, on account of the different rates at which they cool the heated metal. An oil bath is used when the steel is wanted tougher and not excessively hard, as the oil cools the steel more slowly than water. Brine or an acid bath is used when the steel is wanted very hard, as they absorb heat more rapidly than water. For excessively hard work mercury or quicksilver is sometimes used, as it absorbs the heat very rapidly.

In the hardening of steels, the influence of the bath depends upon its temperature, its mass, and its nature, or, to express this in another way, upon its specific heat, its conductivity, its volatility, and its viscosity. With other things equal, the lower the temperature of the bath, the quicker the metal cools and the more pronounced is the hardening effect. Thus water at 60 degrees makes steel harder than does water at 150 degrees, and, when the bath is in constant use, the first piece quenched will be harder than the twentieth, owing to the rise in the temperature of the bath. Therefore, if uniform results are to be obtained, the bath must either be

of a very large volume or be kept cool by some mechanical means; in other words, the bath must be kept at a constant temperature.

A bath consisting of a liquid which volatilizes easily at the highest temperature it reaches, from plunging the metal into it, forms a space filled with vapor around the steel which retards the cooling action of the liquid. Motion of the bath throws off this vapor, as it brings the liquid in contact with the metal and tends to equalize the temperature. To agitate the piece to be hardened gives better results than trusting to the volatility of the bath, as it is more energetic in distributing the vapor.

Quenching Tanks. *Essentials.* The main point to be considered in a quenching bath as mentioned before, is to keep it at a uni-

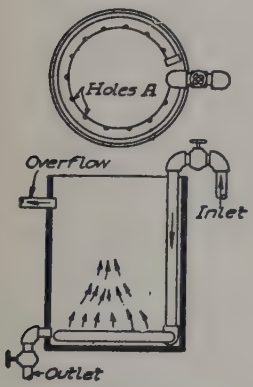


Fig. 175. Common Water or Brine Tank

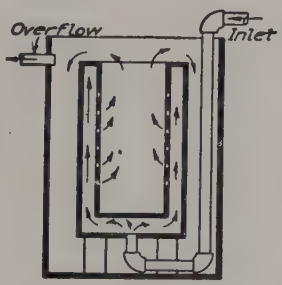


Fig. 176. Double Water or Brine Tank

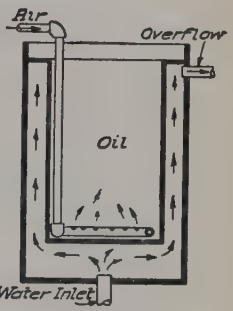


Fig. 177. Oil Quenching Tank

form temperature so that the successive pieces quenched will be subjected to the same heat. The next consideration is to keep the bath agitated, so that it will not be of different temperatures in different places. If thoroughly agitated and kept in motion as in connection with the tank shown in Fig. 176, it is not even necessary to keep the pieces in motion, as steam is not likely to form around the pieces quenched.

Common Tank. In Fig. 175 is shown a common water or brine tank. In this case, the water or brine is pumped from the storage tank and returned to it continuously. If the storage tank contains a large volume of water, there is no need of special means for cooling. The bath is agitated by the force with which the water is pumped

into it. The holes at *A* are drilled on an angle so as to throw the water toward the center of the tank.

Double Tank. In Fig. 176 is shown the water or brine tank of a quenching bath. Water is forced by a pump or other means through the supply pipe into the intermediate space between the outer and inner tanks. From the intermediate space it is forced into the inner tank through small holes as indicated. The water returns to the supply tank by overflowing from the inner tank into the outer one and then through the overflow pipe as shown.

Oil Type. In Fig. 177 is shown an oil quenching tank in which water is circulated in an outer surrounding tank for keeping the oil bath cool. Air is forced into the oil bath to keep it agitated.

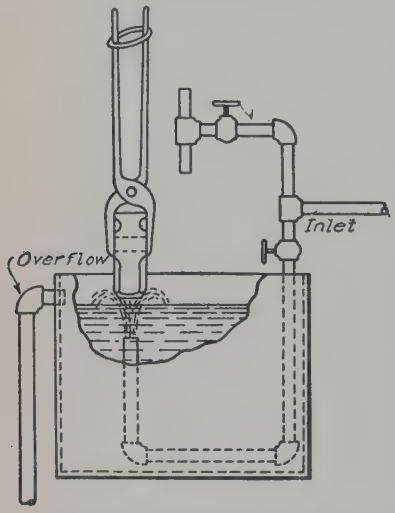


Fig. 178. Quenching Bath Used for Hammers, Etc.

Special Form. Fig. 178 shows a quenching bath used to harden the faces of hammers and all similar tools. The stream of water rising straight from the bottom of the quenching tank strikes the face of the hammer as shown and in this way insures the center being equally as hard as the edges, because steam cannot generate and form a cushion as it would were the tool merely immersed in the water.

Cracks and Fissures. Much serious trouble has been caused by the sudden cooling of the steel. Many times a piece separates abruptly from the part quenched. The reason for this is easily given, as, during the cooling, different parts of the steel are at different temperatures. This is many times caused by thick and thin sections in the same piece, but it also occurs in pieces of an even thickness, owing to the transformation in temperature not taking place everywhere at the same time. This causes internal strains which many times attain enormous value and result in the lessening and also stopping of the cohesive force which holds the molecules of the steel together.

Warping. Warping may be caused by several factors, of which the two most important are: not having the steel in a proper condition of repose before it is hardened; and not putting the piece in the quenching bath properly. As any operation of working the steel is liable to set up internal strains, it is always best after rolling, forging, or machining steel to thoroughly anneal the piece before hardening it. This allows the steel to assume its natural state of repose.

Preventive Rules. There are several rules that can be followed in hardening a piece of steel to prevent warping, and these rules always assume that the steel has been properly annealed before starting the hardening. (1) A piece never should be thrown into the bath, as by lying on the bottom it is liable to cool faster on one side than the other, thus causing it to warp or crack. (2) The piece should be agitated in the bath to destroy the coating of vapor which might prevent its cooling rapidly, and also to allow the bath to convey its heat to the atmosphere as required. (3) Work should be quenched in the direction of its principal axis of symmetry so that the liquid will cover the greatest possible surface at the instant of quenching. A gear wheel should be hardened perpendicularly to its plane, and a shaft vertically. (4) Hollow pieces such as spindles should have the ends plugged, as they could not be quenched vertically on account of the steam which would form in the hole. (5) Pieces with thin and thick sections or of intricate sections, should be immersed in such a manner that the parts of the greatest section enter first. (6) Pieces which are very complicated should be rigged up with hoops, clamps, or supports, to prevent their warping.

Carbonizing

Problem of Casehardening. During the last few years, when the universal aim of the designer and manufacturer has been directed to the highest efficiency of the product, a problem of a peculiar nature is sometimes met.

For a simple illustration, consider a pair of toothed wheels, or a chain and a sprocket, transmitting power. In either case, strength and durability are very essential in order to transmit the power safely and to retain the true surface of the tooth for the sake of good efficiency. It will be readily seen that, in order to meet such conditions satisfactorily, a material of a soft and tough nature should

be employed—something that possesses strength and resistance to wear, and still conforms with standard practice of design regarding the proportions of parts. Such problems have come and have to be met by the manufacturer and the mechanic; they constitute the problem of *casehardening*. It is not a new subject but is one that is not well understood and not always easy to control. This statement is justified by the diversity of opinion among different investigators in regard to the fundamental principles underlying the process of casehardening.

Principles of Process. The process consists, as the name implies, of forming a case of high carbon, which is capable of hardening a surface of a low-carbon steel or wrought iron which in itself has not the property of hardness. The prevailing theory is based on the following principles.

(1) The steel to be carburized must be placed in contact with carbonaceous material.

(2) The high temperature at which the steel and the carbonaceous material is heated gasifies the carbon (if in a solid state) and opens the pores of the steel, allowing the gaseous carbon to penetrate.

(3) The penetration is aided if the gas is under pressure and in the presence of nitrogenous matter acting as a carrier of the carbon.

Carbonizing Materials. The most important factor involved in casehardening is the carbonizing material, for upon this depends quality of case and uniformity of product. The great difficulty at the present time is to obtain a definite uniform result, and to duplicate it at will. Many investigators are engaged in the solution of this problem which eventually will be solved by the discovery of a reliable carbonizing material.

Old Process. In the older process, charred organic matter—such as wood charcoal, charred leather, bone, horn, and the like—was used for packing. Charred leather being rich in nitrogen gave a very good result, but leather scrap became useful for other purposes, thus becoming unavailable for carbonizing. Granulated bone was next resorted to and is used extensively yet, but, owing to its high phosphorus content, it is apt to make parts brittle, and it should be avoided on small parts. Charcoal does not seem to find much favor, although it is fully as efficient as bone if properly prepared.

Opposing Factors. All of the materials mentioned are more or less unreliable for producing the desired effect on the steel. The question then arises, What would constitute a reliable material? Before replying directly, there must be considered the following factors which hinder the carburization of the steel by bone, charcoal, or similar prepared compounds.

(1) Unequal heating of the steel due to the manner of packing. It takes considerable time for heat to penetrate to the center containing the steel and packing; consequently, the parts near the walls of the crucible are heated sooner, and carbonizing begins earlier.

(2) Unequal composition of materials for packing causing variation in the amount of gas, and, therefore, unequal pressure generated in different sections of the crucible or packing box. To obviate this trouble, a packing material of perfectly uniform composition and high conductivity should be used. It should liberate carbon freely, yet not faster than the steel can absorb it. Steel absorbs carbon at certain rates depending on the temperature; high heat gives faster penetration. If an excess of carbon is liberated, the surface of the steel becomes supersaturated with carbon, the result being a brittle structure. The case should not be more than from 0.90 per cent to 1 per cent carbon, which is generally the result if proper heat and good carbonizing material are used. The packing material should be free from sulphur, especially if moisture is present, for sulphur acidifies moisture, and the combined effect produces a scaled pitted surface.

Compounds. There are a number of casehardening compounds on the market claiming one or more of the ideal characteristics. In general these compounds consist of: carbon, volatile matter and hydrocarbon, nitrogen, ash, sulphur, and phosphorus. They are likely to contain silica, alumina, lime, ammonia, and carbonate.

Use of Crucible. *Packing.* The parts to be casehardened should be placed in the crucible in such a way that none of them may come in contact with it, for otherwise the result would be soft spots; there should be a space of at least 1 inch from the wall of the crucible and about $\frac{1}{2}$ inch between the parts.

The packing material should be well tamped down so as to leave no open space. This is a very important and necessary precaution which must be observed to obtain a satisfactory result. After heat-

ing the contents of the crucible, a shrinkage takes place which amounts to about 16 per cent of the total value in the crucible. If the specimens are not packed tightly, some of them, or portions of them, are liable to be exposed and no appreciable carburization will result in the exposed surfaces. This statement simply reverts to the principles involved in carburizing with solid material, viz: There must be solid carbon in contact with the steel, and an intervening gas (CO) to effect carburization.

Sealing. Having carefully packed the specimens, the crucible should be covered with a lid and luted with fire clay. If neglected, this operation would cause an almost total failure—the specimen at the bottom would have a slight case; those on top would not have taken on any carbon. If the crucible is not sealed, the gases formed inside escape, which means, eventually, the absence of one of the principal elements in carburizing, viz, the intervening gas.

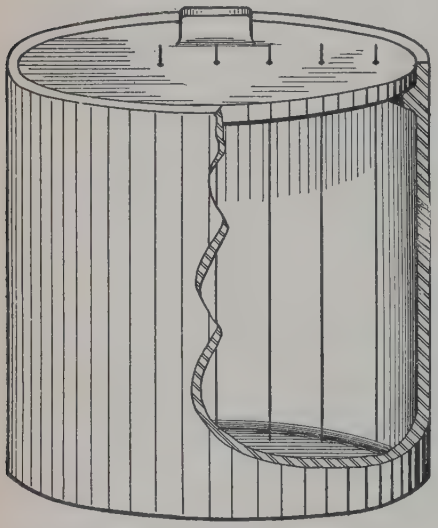


Fig. 179. Use of Test Wires for Timing Heat

Timing. To determine the length of time required for the crucible to heat through, the wire test is the safest. Steel wires $\frac{1}{16}$ inch in diameter are inserted through suitable holes in the cover into the packing mixture. Fig. 179 shows the manner in which they were placed. These wires are drawn one by one at different intervals and the temperature noted from the color of the wire. Suppose the outside wire is drawn and found to be up to heat. The next is drawn, and if not up to heat, as indicated by the color, more time should be given for heating. When the last wire is up to heat, count the time for carburizing.

Crucibles should not be too large. If so, the parts near the crucible wall take on more carbon due to being reached by the heat

TABLE V

Casehardening

Temperature (degrees F.)	Time (hours)	Case	
		Depth (inch)	Carbon (%)
1650	2	$\frac{1}{64}$	0.80
1650	4	$\frac{1}{32}$	1.00
1650	6	$\frac{1}{16}$	1.15

quicker. The average time required for packing the material and heating up the crucible should not be more than $1\frac{1}{2}$ or 2 hours.

Boxes for Packing. Ordinary cast-iron boxes are used mostly in the majority of shops and give good service if the heat used is not too high. Malleable-iron boxes stand a higher heat. If a heat of about 1800 degrees is required, a graphite crucible will give the best results.

General Packing. Observe the customary rules, allowing a sufficient amount of carbonizing material in proportion to the amount of steel to be carbonized. Pack uniformly for uniform results. Shake the box so that the carbonizing material will pack close to the steel. When the last layer of steel has been placed in the box, fill the latter heaping full with carbonizing material and tamp down with a wooden block. Cover the boxes and seal with fire clay.

Re-Using Carbonizing Material. Most of the compounds can be used over several times before being entirely exhausted, in from 50 to 75 hours, so by adding from 20 to 25 per cent of new material to the old each day there will be sufficient to provide for shrinkage and keep the carbonizer up to its normal strength.

Carbonizing Temperature. Most carbonizing material has a carbonizing range from about 1500° to 1800° Fahrenheit. The temperature should be chosen so that the core of the carbonized steel does not crystallize excessively. By observing this precaution, good results can be obtained with a single heat treatment. A temperature of from 1600° to 1700° Fahrenheit will suit the majority of carbon steels; the depth of case and percentage of carbon acquired in various times are shown in Table V.

Carbonizing and Hardening with One Heat. This is not a good practice, but is sufficient for some kinds of work. When this practice is resorted to, the heat must not be above 1600° Fahrenheit, or

the steel will be coarse and brittle. A carbonizing heat of about 1500° Fahrenheit is better though it means a slower penetration.

Fig. 180. Fractures of Steel Bars Showing Various Tests

Heat Treatment after Carbonizing

Shell and Core Distinction. The heat treatment following carbonizing should be done very carefully owing to the fact that the

piece must have a very hard outer surface in order to resist wear and also a non-brittle core which will resist strains.

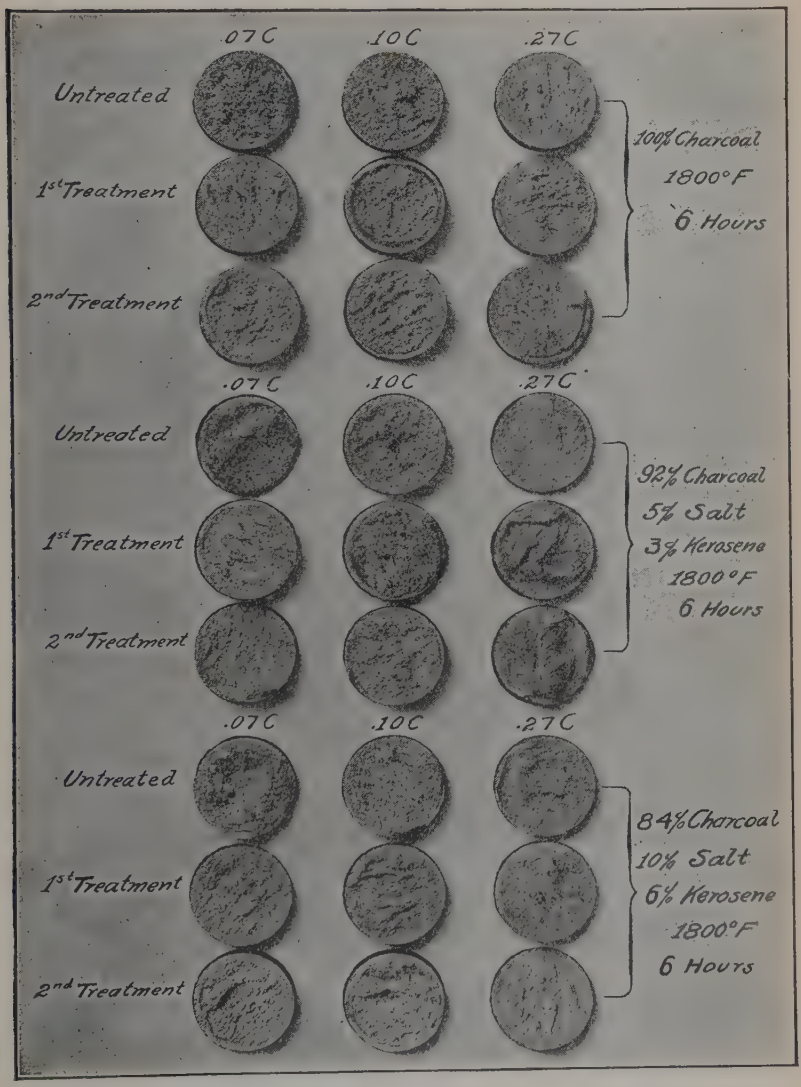


Fig. 181. Fractures of Steel Bars Showing Effect of Heat Treatment after Carbonizing

Double Quenching. For the best results, as the carbonizing temperature is a high one, the piece should be allowed to cool, then

reheated to 1650° Fahrenheit and quenched, and reheated again to 1400° Fahrenheit and quenched.

The reason for the double quenching is that the piece must be heated above its point of transformation to destroy the crystallization and consequent brittleness which is liable to be in the core when it is carbonized at a high temperature; but this leaves the carbonated surface layer not hard enough to resist wear; therefore it must be quenched again at 1400° Fahrenheit.

This point of transformation varies with the different components of the high-grade alloy steels, and should be ascertained before hardening the piece.

By quenching directly from the carbonizing retort a distinct line is formed between the high-carbon outer shell and the low-carbon core, and this is liable to cause the metal to crack on this line, but if the work is properly heat-treated after carbonizing, this distinct line is made to disappear, and the danger of the steel cracking is removed.

Specimens. Fig. 180 shows the fractures of different samples of steel and the effect of time and temperature on the depth of case-hardening of steel with different percentages of carbon.

Fig. 181 shows the effect of heat-treatment after carbonizing. *Untreated* means that the steel was quenched direct from the carbonizing retort, which is too high a heat for good results. *First treatment* shows that steel was allowed to cool and then reheated to 1400° or 1450° Fahrenheit and quenched. This gives a good case but not a good core. *Second treatment* shows the results that come from proper heat-treatment. The steel was allowed to cool, reheated to 1650 degrees, quenched, reheated to 1450 degrees and quenched, which gives both a tough core and a hard fine-grain case.

Cyanide Hardening

Potassium-Cyanide Bath. Some hardeners prefer cyanide of potassium to lead for heating cutting tools, dies, etc. It is a white transparent salt which melts at a fairly low temperature, and should be carefully used as it is a virulent poison. The fumes are very injurious and the furnace should be enclosed with a hood connecting with a chimney or ventilating shaft. This bath is used a great deal in gun shops for hardening certain pieces on which it is wished

to secure ornamental color effects. To get the color effect an air jet is forced up from the bottom of the quenching tank, as shown in Fig. 182, and the air coming in contact with the piece to be hardened gives it a variety of colors.

Casehardening. Casehardening also can be done with cyanide, although no great depth of case is secured. The cyanide is melted in a cast-iron pot in a furnace and then the work to be casehardened is entirely immersed in the cyanide which is heated to a dark cherry red. The work should be suspended by fine iron wires. When the work has been thoroughly heated through, it can be removed and quenched 15 or 20 minutes afterward, and a casing of suitable depth for ordinary purposes is insured. Increasing the length of time of immersion will simply add to the depth of the casing, but 30 minutes of heating will give a very deep casing. The work can be dipped in clear cold water immediately after having been removed from the cyanide bath, or it may be permitted to cool, and may be reheated and hardened in the same manner as in connection with pack hardening. When small pieces are to be heated in cyanide, it is best to use wire baskets, which must be made so that the liquid has free access to all the surfaces of the finished pieces.

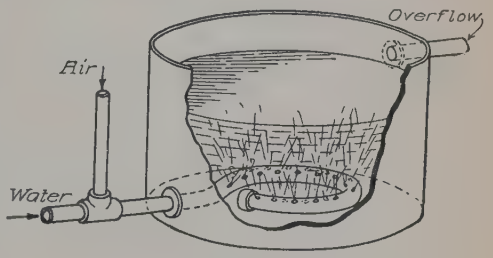


Fig. 182. Quenching Tank

Tool Work

General Laws for Hardening. Because of the many grades of steel now made containing various alloys, it is impossible to give any set rules for hardening as compared with those used at the time when strictly straight carbon tool steel was used for all purposes. The hardening of a carbon steel is due to a change of internal structure which takes place in the steel when heated properly to a correct temperature. The two simple general facts of hardening that may be remembered are: (1) the heat from which the steel is cooled determines the grain; and (2) the rapidity of cooling determines the

hardness, everything else being equal, the more rapid the cooling, the harder the steel.

Hardening Heat. There is only one heat from which the steel may be cooled and have the proper grain, and this is known as the *hardening heat.* A piece of steel when cooled from this hardening heat has an extremely fine silky looking grain and is left very hard and brittle. The hardening heat varies with the amount of carbon the steel contains, the greater the percentage of carbon, the lower the hardening heat.

To determine the hardening heat, a bar $\frac{1}{4}$ inch or $\frac{3}{8}$ inch square is heated to a good red heat on one end, and cooled in cold water. This end is then tested; if too hard to file it has been hardened, and the heat from which it was cooled was either the proper hardening heat or some higher heat. If the end can be filed, it was cooled from some heat below the hardening heat. If the end proves to be soft, it should be rehardened by cooling from a higher heat, if hard, it should be broken off and the fracture examined. If the grain of the broken end is very fine, the steel is properly hardened, if coarse, it was heated too hot and the end should be rehardened at a lower heat. The experiment should be repeated until the operator is able to give the steel a very fine grain every time. Any variation either above or below the hardening heat will make the grain coarse. A temperature lower than the critical heat will not make the steel as coarse in structure as a temperature correspondingly higher, but there will be some difference.

Self-Hardening Steel. Self-hardening steel is used to a large extent in modern practice for lathe tools, much being used in the shape of small square steel held in special holders, as illustrated in Fig. 183. Self-hardening steel, as its name indicates, is almost self-hardening by nature, generally the only treatment that is required to harden the steel being to heat it red hot and allow it to cool. Sometimes the steel is cooled in an air blast or is dipped in oil. It is not necessary to draw the temper. The self-hardening quality of steel is given to it by the addition of chromium, molybdenum, tungsten, or one of

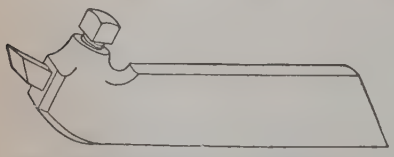


Fig. 183. Typical Tool Using Blade of Self-Hardening Steel

that group of elements, in addition to the carbon which ordinary tool steel contains. High speed steel is lower in carbon.

Self-hardening steel is comparatively expensive, costing from 40 cents and upward per pound, some of the more expensive grades costing $1 or so. However, when in use, self-hardening steel will stand a much higher cutting speed than the ordinary so-called carbon steel, and for this reason it is much more economical to use, although its first cost is higher.

Self-hardening steel cannot be cut with a cold chisel and must be either cut hot or nicked with an emery wheel and snapped off. Great care must be used in forging it, as the range of temperature through which it may be forged is comparatively slight, running from a good red heat to a yellow heat. Some grades of self-hardening steel may be annealed by heating the steel to a high heat in the center of a good fire and allowing the fire and the steel to cool off together. Steel which has been annealed in this way may be hardened by heating to the hardening heat and cooling in oil.

Taylor-White Process. This method of treating special grades of self-hardening steel was discovered some years ago by the men after whom it is named. It was found that if a piece of self-hardening steel is heated to a very high temperature (about the welding heat) and then suddenly cooled to about a low red heat, the steel would be in a condition to stand very much harder usage and take a much heavier cut. Steel treated in this way seemed to have the cutting edge of the tools almost burned or melted off and considerable grinding was necessary to bring them into shape. When put in use the edges would almost immediately be slightly rounded or crumble off, but after this slight breaking down of the cutting edge, the steel would stand up under excessively trying conditions of high speed and heavy cut. Tools of this character are of very little or no use for fine finishing, but are of great value for heavy and roughing cuts.

Hardening High-Speed Steel. High-speed steel has a much higher critical temperature than carbon steels. A temperature of about 1350° to 1600° Fahrenheit is sufficient for carbon steels in general. High-speed steels require heating from 1800° to 2300° Fahrenheit, and to be cooled in oil such as machine, fish, or linseed. Steel of this nature is close grained and should be heated slowly

until red, then forcing the heat faster up to dazzling white. When it shows signs of melting down it should be quickly put in the cooling bath. The treatment varies for the different steels, and it is advisable to get directions from the steel maker as to the treatment, which varies according to the alloys of the steel. Air blast formerly was recommended by some steel makers, but at present oil is most extensively used.

Barium-Chloride Bath. A barium-chloride bath for heating high-speed steel has been used by some manufacturers for finished tools such as milling cutters, taps, and drills. To get the high heat required without oxidizing, a thin coating of the barium chloride is formed on the steel, which, in transferring from the heating bath to the oil bath, keeps the steel from coming in contact with air and thus avoids oxidation. One trouble with the barium chloride is that a thin surface about 0.008 inch thick is soft, but for cutters that have to be ground this disadvantage is of no account.

Special Shapes. For tools with special shapes that cannot be ground—such as gear cutters, twist drills, taps, threading dies, and many other tools not permitting grinding after hardening—a muffle furnace is best to use, as in this furnace tools do not come in contact with the flame and the thin cutting points are thus more protected.

Measuring and Testing Instruments

Pyrometers. All up-to-date hardening rooms now are equipped with pyrometers in order to insure uniformity of the heat in the furnaces, and also uniform results in the hardened products.

There are various types of pyrometers, depending upon different principles for their workings such as the thermoelectric, resistance, radiation, and others. The most commonly used is the thermo-electric type. In this type, the temperature variations are determined by the measurement of an electric current generated by the action of heat on the junction of two dissimilar metals, that is, when one junction of the thermo-couple has a temperature different from the other, a current is developed which indicates on a meter.

Thermoelectric Type. Fig. 184 shows the outlines of the parts of a complete Wm. H. Bristol thermoelectric pyrometer, with the fire end applied for measuring the temperature in a bath of molten lead. This particular fire end is bent so that the tip *A*, where the

elements are welded together and the temperature is measured, may be submerged in the molten metal and the fire end joined to the extension piece at the point *C*, so as to carry the cold end *D* of the thermo couple *ABCD* to a point of constant temperature.

Method of Installing. Fig. 185 shows the method of installing a pyrometer in a muffle type of furnace with the fire end projecting through a hole in the rear wall. The fire end is provided with two iron-pipe protection tubes, so that when the outer pipe scales away through action of the heat, this can easily be replaced without injury to the elements of the fire end or its inside protection pipe. The diagram shows the extension piece installed horizontally so

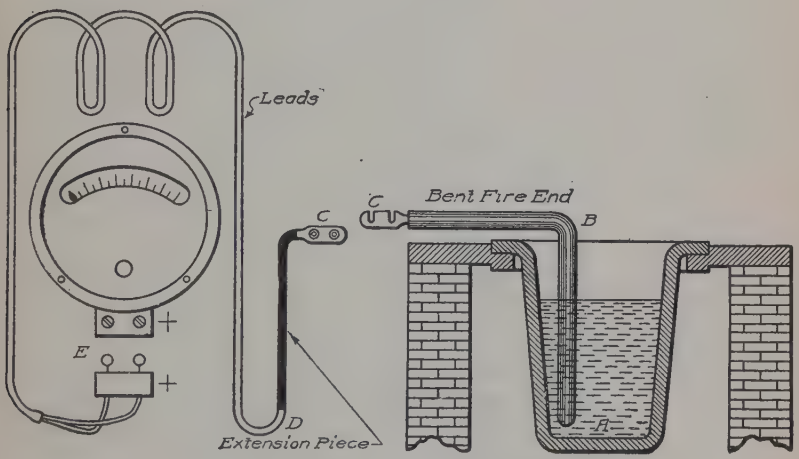


Fig. 184. Diagram Showing Layout of Electric Pyrometer

that it affords a practical method of keeping the cold end of the couple below and away from the influence of the variations of temperature in the furnace.

Accurate Use. As the temperature is measured at the tip of the fire end, the end should project far enough into the furnace to become thoroughly heated through. With the pyrometer to guide him, the operator can hold the right temperature in the furnace and make sure the work is heated up to this temperature by comparing its color with that of the tip of the fire end. For accurate results the cold end of the connection should be kept at a temperature of about 75° Fahrenheit.

It seems to be the general opinion among some people that pyrometers are not of much use in hardening, that they do not give accurate readings, and that better results can be attained by depending upon a man's experience. It is quite true that an experienced

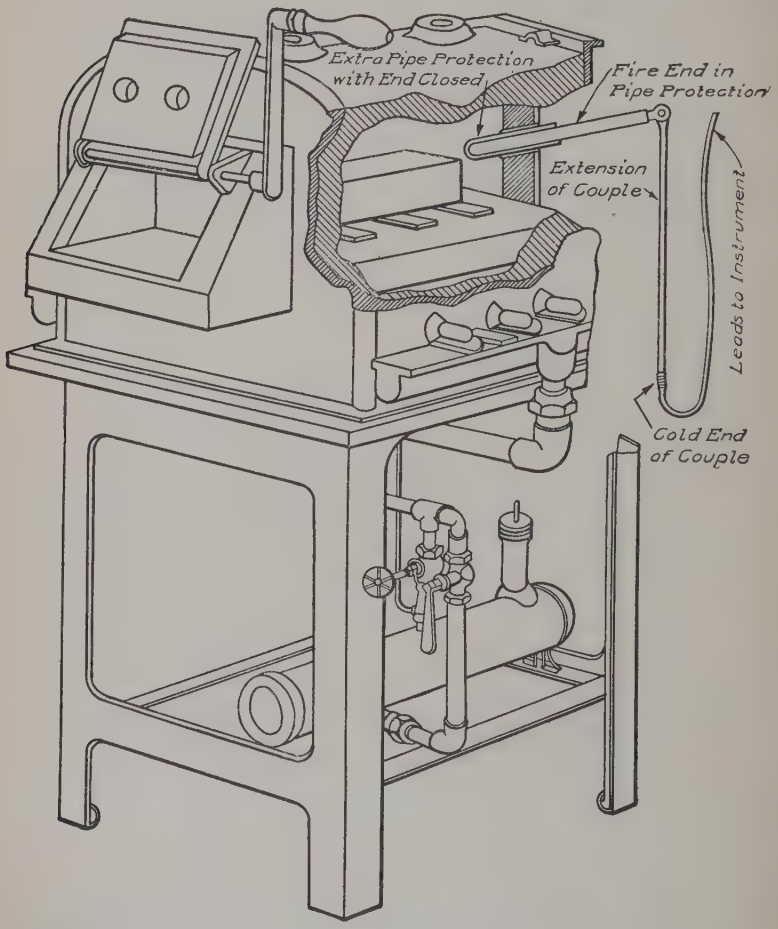

Extra Pipe Protection with End Closed
Fire End in Pipe Protection
Extension of Couple
Leads to Instrument
Cold End of Couple

Fig. 185. Part Section Showing Method of Installing a Pyrometer in a Furnace

man's eye is a good means for judging the heat in a furnace and may be far better than an incorrectly calibrated pyrometer. However, by frequent calibration it is possible to keep the pyrometer in such condition that the readings are a great deal more accurate than any estimate of heat by the eye.

Hardness Testing. Few properties of iron and steel are of more importance than that of hardness, and even as far back as when men first began to harden steel, they probably sought some method of testing for hardness. Although the file test for hardness is used extensively today, it is not considered accurate. In regard to methods for testing hardness, it might be well to mention four, though of these four there are only two that are very well known

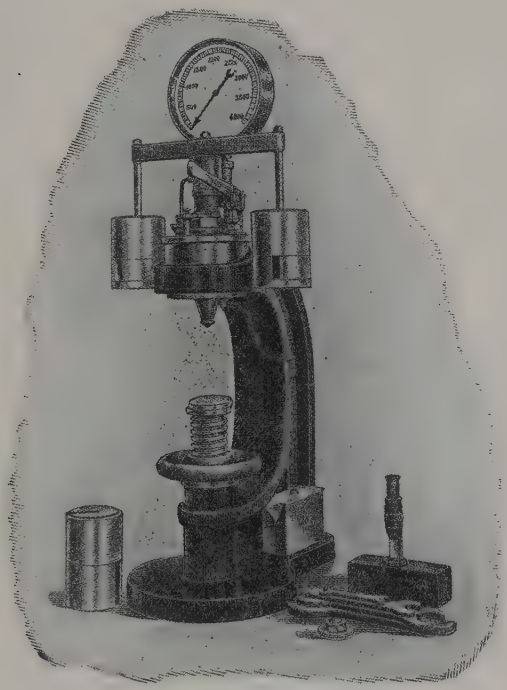


Fig. 186. Brinell Hardness Tester

and that are most commonly used—the Brinel. test, brought out in 1900, and the Shore test, brought out in 1907.

Sclerometer. In 1886 Prof. Thomas Turner brought out the sclerometer. In this form of test a weighted diamond point is drawn across a smooth surface two or three times and the hardness number is the weight in grams required to produce a standard scratch.

Drill Test. Keeps testing is known as the drill test and was introduced in 1887. In this form of apparatus a standard steel drill

is caused to make a definite number of revolutions when pressed with various standard forces against the piece to be tested. The hardness is automatically recorded on a diagram.

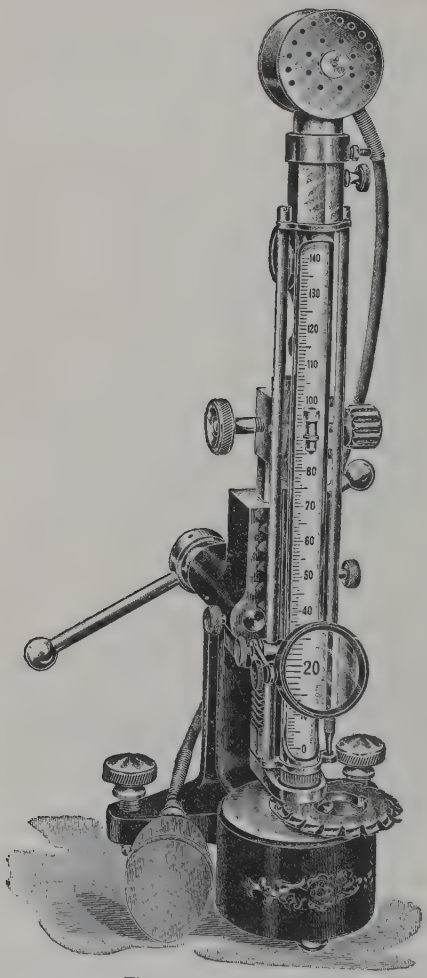


Fig. 187. Scleroscope Testing Set
Courtesy of Shore Instrument Company, New York City

Brinell Tester. Fig. 186 shows the Brinell method. In this method a hardened steel ball is pressed into a smooth surface of the metal so as to make an indentation which is measured by a microscope. The spherical area of the indentation being calibrated and the pressure being known, the stress per unit of area when the ball

comes to rest is calculated, and then the hardness number is obtained.

The machine, Fig. 186, is an hydraulic press with a downwardly acting ram carrying the ball which is pressed into the test piece; the manometer shows the pressure of the oil.

Shore Scleroscope. Shore's scleroscope consists of a small cylinder of steel with a hardened point which is allowed to fall upon the

Fig. 188. Method of Testing Sheets and Flats
Courtesy of Shore Instrument Company, New York City

smooth surface of the metal to be tested, and the height of the rebound of the hammer is taken as the measure of hardness. The hammer weighs about 40 grains, the height of the rebound from hardened steel is in the neighborhood of 100 on the scale.

While the absolute weight of the entire hammer is little, it is very great relative to the striking area. The hammer is guided in its fall by a glass tube. The glass tube is secured to a frame in a vertical position with the lower end upon the test piece.

Fig. 187 shows a complete testing set, and Figs. 188 and 189 the different methods of applying the instrument to different kinds of work.

Fig. 190 gives a general view of the working parts. In the scleroscope action the vital part is the diamond faced drop hammer which must always be raised to its hanger hook at the top where it remains in readiness for the test. In the automatic instrument

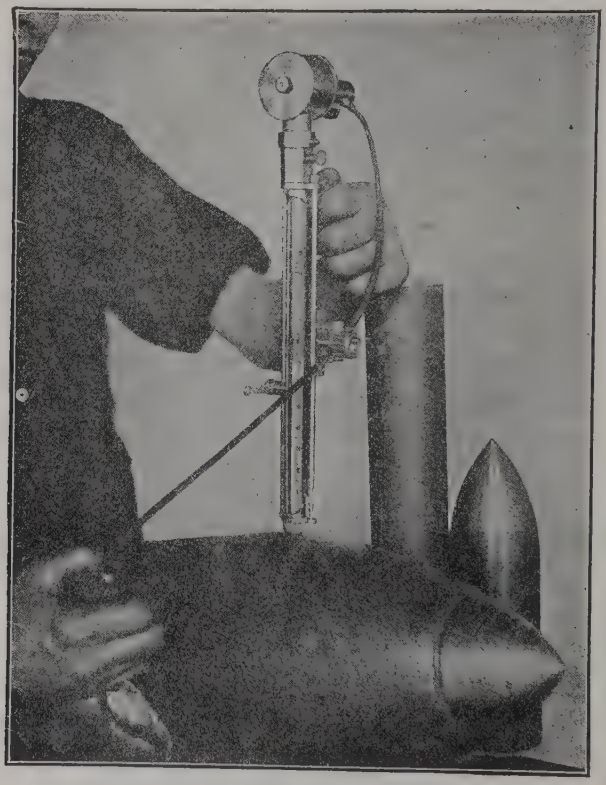


Fig. 189. Testing Hardness of Projectiles
Courtesy of Shore Instrument Company, New York City

now manufactured, the necessary valves, the suction for the hammer and its release all are operated alternately by one bulb acting on the cam *B*, Fig. 190, through the medium of the piston *C*, the adjustable oscillator *D* and the end ratchets *E*. When the hammer is down it will be found impossible to suck it up by the vacuum formed on releasing the hold on the bulb because the valve is then wide open and is held so by the cam *B*.

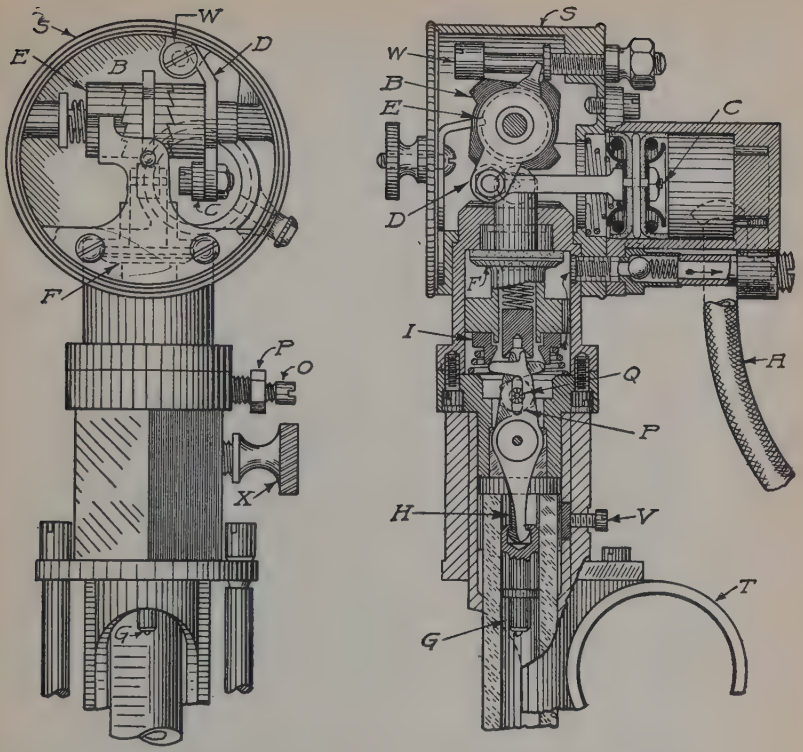


Fig. 190. Detailed Drawing Showing Parts of Shore Scleroscope

TEMPERING

Essentials of Process. To temper steel is to return it to a state of molecular equilibrium at atmospheric temperature by relieving any strains in the metal which have been caused by sudden quenching, and also to correct any exaggeration of certain properties which have been caused by the hardening process. In other words, the object of tempering is to reduce the brittleness in hardened steel, and to remove the internal strains caused by the sudden cooling in the quenching bath. The tempering process consists in heating the piece of work by one of various means to a certain temperature, and in permitting it to cool gradually.

Temperature Conditions. The temperature to which a piece should be raised for tempering depends on several conditions: the use to which it is to be put; the condition in which it has been left by

quenching; and the composition of the steel. The degree of heat to which the tool to be tempered is heated determines the degree of toughness it has attained—the higher the tempering heat, the less brittle, and also the less hard, the tool is. The maximum temperature desired need be maintained only long enough to be sure the piece is heated evenly. Steels which are reheated slightly after hardening give a freedom to the molecular change that lessens the molecular rigidity set up by the hardening process.

Reduction of Brittleness. Tools are always left as hard as it is possible to leave them and still have them tough enough for the work for which they are intended. In reducing the brittleness of the steel, some of the hardness is of necessity taken out, and tempering is therefore sometimes spoken of as a reduction of the hardness, but it is in reality merely a reduction of the brittleness. After a tool or piece of steel has been hardened, some of the brittleness is taken out by a slight reheating to a low temperature. These temperatures vary from 200° Fahrenheit, to about 650° Fahrenheit, and are determined in various ways. The simplest and perhaps the most commonly used method is to polish the steel after it has been hardened and then to reheat the part to be tempered until the surface shows a certain color.

If any bright piece of iron or steel is heated, when a temperature of about 400° Fahrenheit is reached, the surface turns pale yellow. As the temperature is increased, this yellow grows darker until at about 500° Fahrenheit it is a decided brown. When 600° Fahrenheit is reached, a deep blue color shows on the surface. These colors are produced by a thin scale which is formed on the surface of the steel and are no indication whatever of hardness, merely showing to what heat steel or iron has been raised.

Baths for Tempering. As the object of tempering is simply to reduce the brittleness and to remove the internal strains caused by the sudden cooling in quenching, the composition of a tempering bath is of little importance as compared with that of a quenching bath. Aside from the operator's convenience and the possible bad effects upon his health, the different baths used for this operation must be considered chiefly with regard to initial cost and lasting quality, and also effect on finish.

Various Mediums. The two main points to be considered

when using an oil tempering furnace are: (1) to have the heat uniform throughout; and (2) to leave the pieces to be tempered in the oil long enough to have attained the heat of the oil throughout when they are taken out. While oil is the most widely used medium for tempering tools in quantities, other means and methods are employed, especially by those who have tools to temper in small quantities when the expense of installing and running an oil tem-

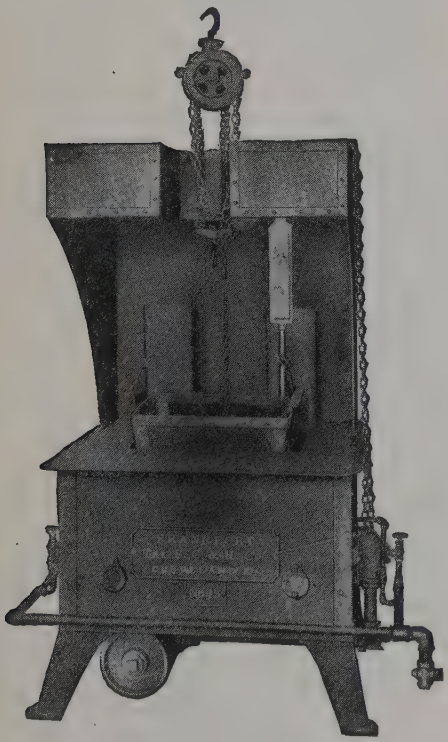


Fig. 191. Typical Tempering Furnace
Courtesy of Strong, Carlisle and Hammond Company, Cleveland, Ohio

Fig. 192. S. C. and H. Company Thermometer

pering furnace would not be warranted. First there is the old-style tool hardener's method of only partly cooling the tool when quenching, then quickly withdrawing it, polishing off the working surface, and letting the heat which remains in the tool produce the required temper as judged by the color. Heated sand is also used to produce the temper, likewise using the color scheme as a medium for judging the degree of hardness. Another common method is

to heat the steel in a bath of red hot lead. The lead is heated in a pot or crucible, to the hardening heat of the steel. The top of the lead is covered with powdered charcoal or coal to prevent the formation of the slag or dross on top. When steel is heated in lead it must be perfectly clean, dry, and free from rust.

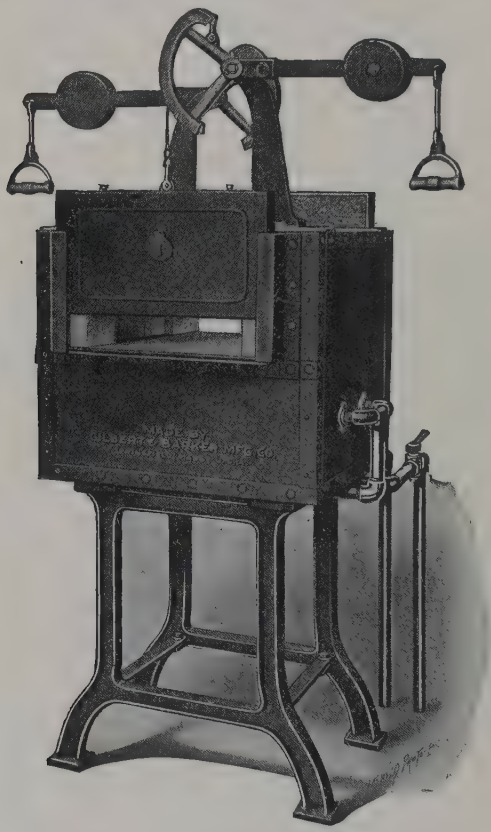


Fig. 193. Double Door Furnace for Heating and Annealing Work
Courtesy of Gilbert and Barker Manufacturing Company, Springfield, Massachusetts

Tempering High-Speed Steel. Tools of large size and for hard usage, such as lathe and planer tools, do not require to be tempered, and should be cooled in thin oil such as lard or kerosene oil. In using kerosene oil care should be used not to let a red-hot part be above the surface of the oil, as it will flash; such a piece should be kept in the bath until cooled to the temperature of the oil. Tools

like milling cutters, drills, reamers, taps, are generally tempered at from 400° to 500° Fahrenheit, depending on the size, as small tools of the same kind require letting down a little more on hardness.

Furnaces for Tempering. In tempering furnaces, as in all other kinds of furnaces, the really important consideration is to

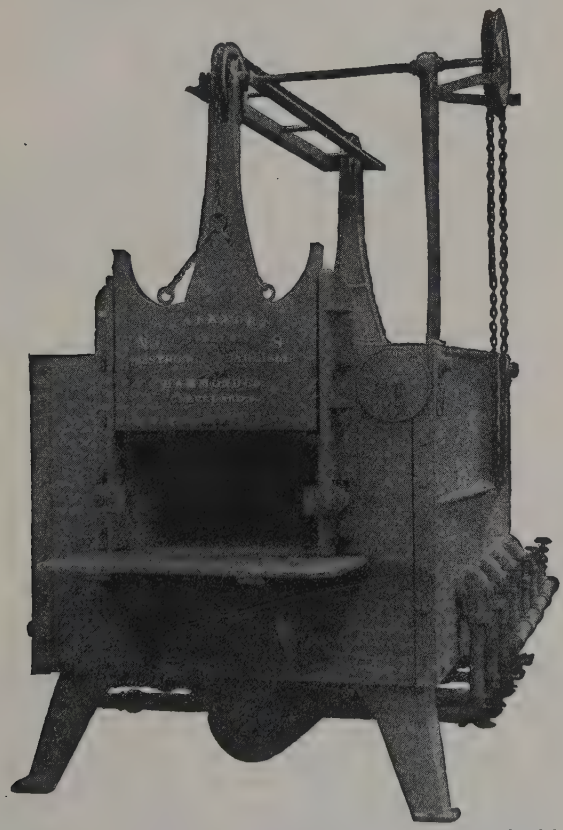


Fig. 194. Large Size Furnace for Heating, Annealing, and Carbonizing
Courtesy of Strong, Carlisle and Hammond Company, Cleveland, Ohio

insure that the furnace is so built as to heat the bath uniformly. The furnaces for tempering are practically the same as the ones used in hardening; those are the best which permit of maintaining a constant temperature and have appliances for measuring the heat so that the correct temperature can be attained.

Fig. 191 shows an ordinary type of tempering furnace. The general principles of combustion are the same as for the average

oil burning furnace, and the tools to be tempered are laid in the receptacle which is immersed in the oil. Fig. 192 shows a thermometer for indicating the temperature of the oil bath. The thermometer is very much like the ordinary mercury thermometer except that it registers as high as 500° to 700° Fahrenheit.

Special Operation. In Figs. 193 and 194 are shown furnaces for heating, annealing, and carbonizing. The burners enter the

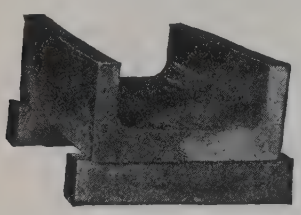


Fig. 195. Bottom Brick of Semi-Muffled Furnace
Courtesy of Strong, Carlisle and Hammond Company

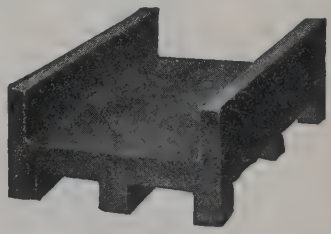


Fig. 196. Furnace Bridge
Courtesy of Strong, Carlisle and Hammond Company

combustion chamber underneath the heating oven; the flame strikes a baffle and the tile floor of the oven, and absolute combustion takes place. Heat free from oxidizing properties is produced and is diverted to the heating oven above with a reverberating motion, which produces a uniform circulation; all materials are thoroughly and uniformly heated. The surplus heat is vented through ports on top of the furnace which can be utilized for pre-heating or for tempering. Blowers are usually mounted upon brackets in the rear, or they may be placed in any other convenient location. The air receiver is underneath, and compressed air may be used when reduced to the proper pressure.

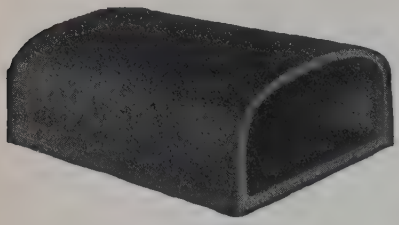


Fig. 197. Brick for Muffled Furnace
Courtesy of Strong, Carlisle and Hammond Company

Advantages of Oil and Gas Types. Oil- and gas-fired furnaces are a great improvement over coke and coal furnaces, as with the latter it is almost impossible to regulate heat to a desired and given point, to say nothing of the inconvenience of shoveling coal and of cleaning out ashes, while dust and dirt that accumulate from these operations are, to say the least,

very disagreeable. Then again, steel heated in such furnaces is more liable to scale or oxidize and to absorb some of the sulphur and

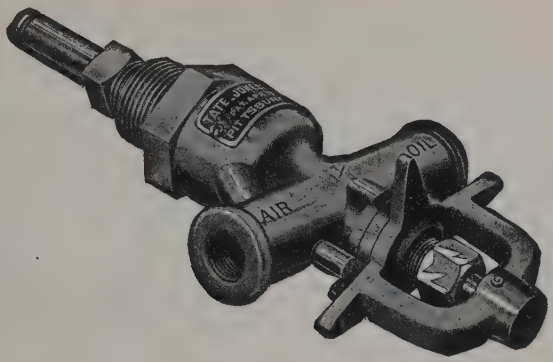


Fig. 198. Oil Burner without Air Blast Connection
Courtesy of Tate, Jones and Company, Pittsburgh, Pennsylvania

other impurities that arise from the combustion. It is a well-known fact that steel absorbs those injurious elements readily at a heat high enough for hardening and working. In a good gas or oil furnace the heat can be very closely regulated, so that the variation is not more than 10 or 15 degrees, which is close enough for most ordinary work.

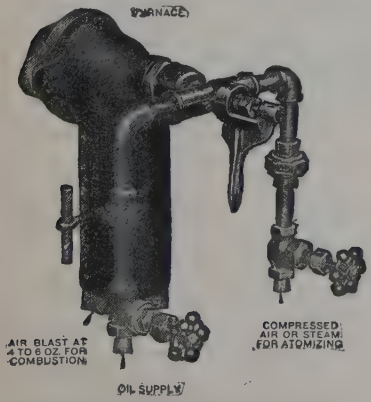
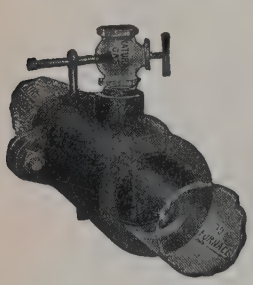
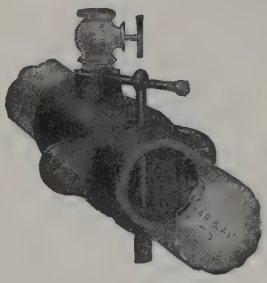


Fig. 199. Oil Burner with Air Blast and Compressed Air and Steam Connection for Atomizing
Courtesy of Tate, Jones and Company, Pittsburgh, Pennsylvania

Fig. 200. Burner Similar to Fig. 199, with Natural Gas Connection
Courtesy of Tate, Jones and Company, Pittsburgh, Pennsylvania

Oil-Burning Furnace. Although the installation is more costly than that of a gas furnace, oil furnaces are used a good deal for economy by large concerns. A storage tank under ground is generally used together with a pumping system to maintain a pressure





Figs. 201 and 202. Front and Back View of Gas Burner
Courtesy of Tate, Jones and Company, Pittsburgh

Fig. 203. S., C. and H. Cast-Iron Pot

sufficient for forcing the oil to the furnace. The oil flows through a simple regulating valve and is immediately atomized with either steam or air at a pressure of from 35 to 100 pounds per square inch. At this point it enters the forcing hood in the form of fine mist where a volume of air at a pressure of about 6 to 15 ounces per square

Fig. 204. Cast-Iron Pot Used for Lead Pot

Fig. 205. Wire Basket for Immersing Work in Oil Bath

inch carries it along the combustion chamber in which it ignites and burns with an intense heat.

A good design of burner should have eliminated the troublesome features of sputtering and dripping oil, which cause an irregular flame. The flame should be clear, white, and free from smoke, soot, and dirt.

Details of Muffle Furnace. In Fig. 195 is shown the bottom brick of a semi-muffle furnace. Fig. 196 shows another brick which is called the furnace bridge. Fig. 197 shows the furnace brick for

this furnace. The heating chamber is enclosed entirely. Parts to be heated do not come in contact with the furnace flame.

Burners. In Fig. 198 is shown a burner without blast connections for use where air blast is not available. This is used by attaching the burner in such a way that air for combustion is drawn into the furnace by the injector effect of the atomized oil. In Fig. 199 is shown an oil burner with blast connections. The supply of oil and the compressed air for atomizing are regulated by one lever. Fig. 200 shows the same burner with natural gas attachment. This burner is just as efficient a gas burner as it is an oil burner. Figs. 201 and 202 show different views of gas burners. An air blast is introduced in the back of the burner.

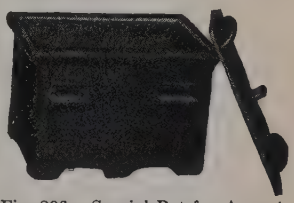
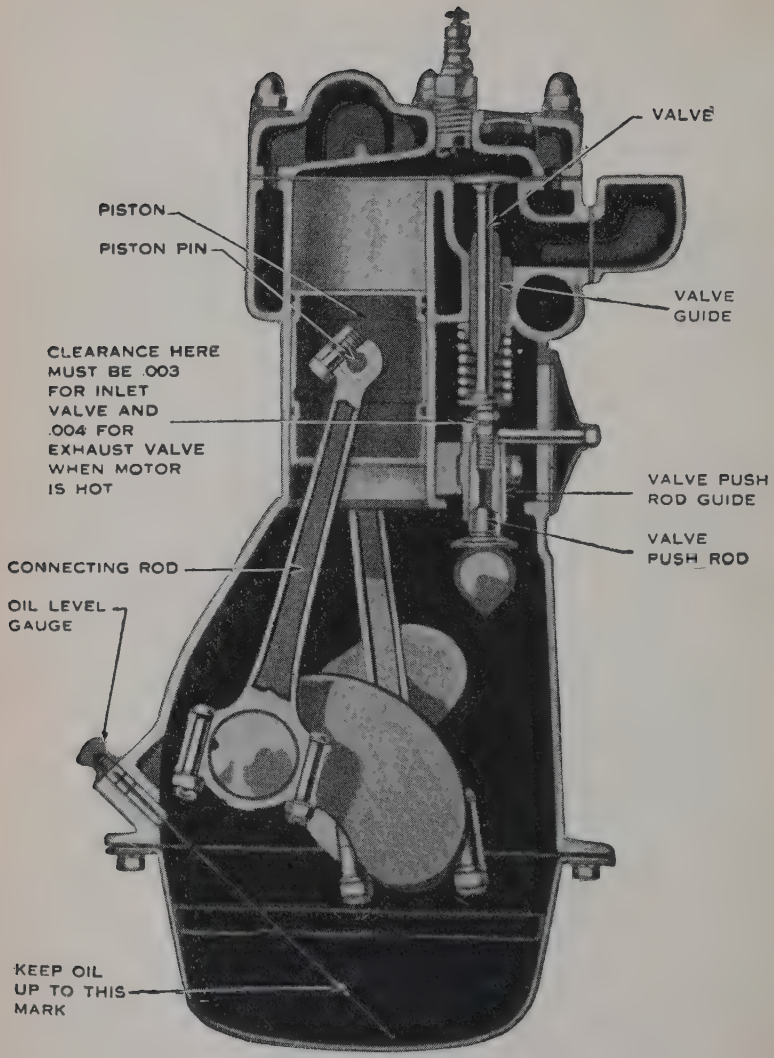


Fig. 206. Special Pot for Annealing or Casehardening
Courtesy of Strong, Carlisle and Hammond Company, Cleveland, Ohio

Containers. Fig. 203 shows a cast-iron pot which can be used for a number of things. Fig. 204 shows a cast-iron pot used for a lead pot. Fig. 205 shows a wire basket for immersing work to be tempered in the oil bath, or it may be used as a basket for holding small tools after hardening. Fig. 206 shows a pot for either annealing or casehardening.


VALVE
PISTON
PISTON PIN
VALVE GUIDE
CLEARANCE HERE MUST BE .003 FOR INLET VALVE AND .004 FOR EXHAUST VALVE WHEN MOTOR IS HOT
VALVE PUSH ROD GUIDE
VALVE PUSH ROD
CONNECTING ROD
OIL LEVEL GAUGE
KEEP OIL UP TO THIS MARK

Cross-Section of Engine
Rickenbacker Motor Company

MECHANISM

The study of mechanism is the study of the laws that govern the motions and forces in machinery. Pure mechanism deals only with the amount and kind of motions, without regard to the forces transmitted, and in this instruction paper only this branch of the subject will be considered. That is, we shall study how to proportion the parts to get the proper motions. Knowing this, the principles of machine design and strength of materials will teach us how large the parts must be to stand the stresses which come upon them.

A Mechanism is a group of parts so shaped and arranged that a definite motion of one part will give other definite motions to the other parts.

A Machine is a combination of mechanisms each of which may be doing a different kind of work, but the whole combination of mechanisms working together accomplishes some desired result. Take for example, a metal planer; the result which is to be accomplished is the planing of a piece of metal, but in order to do this, several auxiliary results must be accomplished. The table or platen, to which the metal is fastened must be moved back and forth, the tool must be fed forward after each chip has been cut, and various other motions produced. There are certain pieces in the planer whose sole work is the moving of the platen, and all these pieces taken together form one mechanism; in like manner, there are certain parts whose sole work is feeding the tool forward each time, and all these parts taken together form another mechanism. All the mechanisms when brought together form the machine.

MOTION.

An object which is changing its position is said to be in motion and an object which is not changing its position is at rest.

Absolute and Relative Motion. If a man is moving along in a sail boat without changing his position in the boat, both man and boat have what is usually spoken of as absolute motion, that

is, they are both changing their position with respect to the earth and water around them. They both change their position in the same direction and at the same rate however, so that they are at rest with respect to each other. If now, the man should start to walk forward in the boat, he would change his position with respect to surrounding objects faster than the boat and he would have motion relative to the boat. We thus have two kinds of motion, absolute and relative; absolute motion being the motion of a body with respect to some fixed object, and relative motion being the motion of one moving body with respect to another moving body.

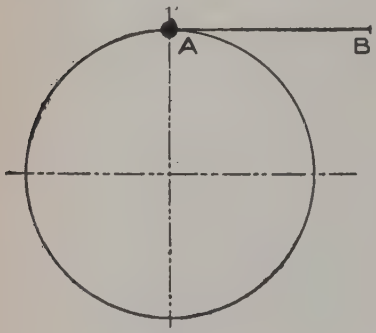


Fig. 1.

Fig. 2.

Since every object has more or less size and therefore can not be represented on paper as readily as can some particular point or line in the body, as far as possible in our study of the motions of bodies we shall consider points and lines, in place of the bodies themselves.

Velocity is the rate of motion. If a bullet travels through the air at the rate of one hundred feet in a second, it has a velocity of one hundred feet per second.

Direction of Motion. A point may have motion in a straight line, in a circle, or in any other curve. The tendency of any body which is in motion is to continue to move in a straight line unless caused to leave that path by some force applied to the body. The direction of the straight line in which a point is moving is called the direction of motion of the point. If an object is traveling in a circle, the direction of its motion at any given instant is the straight line tangent to the circle at the point where the object

is at the given instant. For example, if the point A, Fig. 1, is moving around the circle, the direction of its motion, when in the position shown, is the line AB. In the same way in Fig. 2, if the point A is moving in the curved path, its direction when in the position indicated is the line AB.

By choosing a convenient scale, as one inch equals one foot, or one inch equals ten feet, etc., depending upon how large the velocities are with which we have to deal, the line may be drawn of a length that will represent the velocity of the point A. Suppose the circle, Fig. 1, to have a circumference of ten inches, and suppose the point A to be traveling around the circle at such a speed that it goes around once in five seconds; then, since it travels ten inches in five seconds, it has a velocity of two inches per second. Accordingly, if we draw the line AB two inches long, tangent to the circle at any given position of A, the line AB represents the direction and velocity of A at the instant under consideration. Of course, the direction of motion of a point which is moving in any path other than a straight line is constantly changing, but the direction in which it is moving at a given instant is the direction which it would take if the forces which constrain it to move in the curved path were removed at that instant.

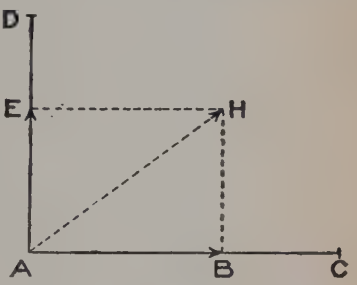


Fig. 3.

Composite Motions. In Fig. 3, let A represent a body lying on a table; suppose AC and AD are strings making a right angle with each other. First, let the string AC be pulled with such force that it will cause A to move one inch in the direction AC, in one second; then A will be at B at the end of a second, the line AB representing the direction and velocity of A when the string AC is pulled. Next, suppose the body to be back in its original position A, and that the string AD is pulled with such force that it will cause A to move $\frac{3}{4}$ of an inch in the direction AD in one second; then at the end of a second A will be at E, the line AE representing the direction and velocity of the body when the string AD is pulled.

Again, suppose both strings to be pulled at the same time, with the same force as before. Then the pull on AC will still cause A to move toward C with a velocity AB, and the pull on AD will cause A to move toward D with a velocity AE, so that at the end of a second the body will be at neither E nor B, but at some point H, whose position is at a distance BH from B, the line BH being equal and parallel to AE. The point H is also at a distance EH from E, the line EH being equal and parallel to AB. In other words, the path over which the body has moved is the line AH, which is the diagonal of a parallelogram whose sides are equal to AB and AE respectively. The lines AB and AE, which represent the velocities caused by the pulls on the respective strings, must be drawn to the same scale, that is, if the pull on AC causes a velocity of one inch per second and

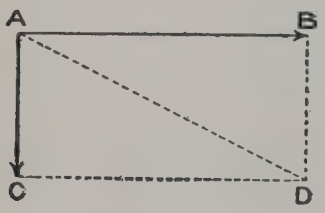


Fig. 4.

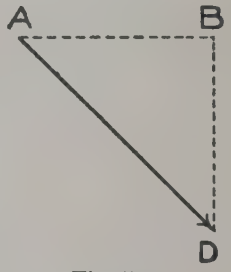


Fig. 5.

the pull on AD causes a velocity of $\frac{3}{4}$ inch per second, AE must be $\frac{3}{4}$ as long as AB.

The velocities AB and AE are called *component velocities*, and the velocity AH the *resultant*.

Let us take another example. Suppose a ball is thrown toward the east with a velocity of ten feet per second, and the wind carries the ball toward the south with a velocity of five feet per second. Let us find graphically how fast and in what direction the ball is actually moving. Using any convenient scale, draw the line AB, Fig. 4, to represent ten feet, and the line AC to represent five feet at the same scale, AC being at right angles to AB, since south is at right angles to east. From C draw CD parallel to AB, and from B draw BD parallel to AC meeting CD at D; then AD, the diagonal of the rectangle thus formed, gives the

direction and the velocity, at the same scale as before, of the actual motion of the ball.

The preceding process is called *composition* of velocities; that is, if we know the velocity of a body in two directions at right angles to each other, we can find from these the real velocity and direction of the motion. Quite as frequently we have given the real direction and velocity and wish to find the velocity parallel and at right angles to some given line. Thus, suppose we know that a ball is moving at a speed of one hundred feet per minute toward the southeast and we wish to know how fast it is moving towards the east. Draw the line AD, Fig. 5, to represent one hundred feet, at a convenient scale; then draw the line AB, making with AD the same angle that a line running southeast makes with a line running east (that is, 45 degrees). From D draw DB perpendicular to AB, meeting AB at B; the length of AB represents, at the same scale at which AD was drawn, the velocity of the ball in an easterly direction, and BD represents its velocity in a southern direction. This is called the *resolution* of velocities, the velocity AD being resolved into two components, one in the direction AB, and one perpendicular to this direction.

*EXAMPLES FOR PRACTICE.

1. If a steamer travels 91,200 feet per hour, what is the velocity in feet per second?

Ans. 25.33 feet.

2. If the piston of an engine moves at the rate of 12.5 feet per second, what is the piston speed in feet per minute?

Ans. 750 feet.

3. A steamer is moving eastward at a speed of 800 feet per minute and the wind and tide carry it north at the rate of 100 feet per minute. Find graphically how fast and in what direction the steamer is actually moving.

Ans. 810 feet per minute.

4. A ball is thrown, with a velocity of 50 feet per second, across a stream 100 feet wide. The wind carries the ball up stream 10 feet per second. How far up stream from the point at which the ball was aimed will it strike? Ans. 20 feet.

*NOTE. Problems 3, 4, 5 and 6 are to be solved graphically.

5. A platform is set up at an angle of 30 degrees with the horizontal, and a weight is allowed to slide down the platform at a speed of ten feet per second. How long will it take the weight to get 10 feet below the point from which it started?

Ans. 2 seconds.

6. The horizontal component of the velocity of a body is 26 feet per minute. If the actual velocity is 52 feet per minute find graphically the vertical component.

Ans. 45 feet per minute (about).

7. A man is on a railway train which is moving at the rate of 25 miles per hour and walks toward the rear of the train at the rate of 88 feet per minute. How fast is the man actually moving?

Ans. 24 miles per hour.

Temporary Center of Revolution. In Fig. 6, let AB represent a bar that forms some part of a mechanism, and suppose that for the moment the end B has a velocity in the direction of and equal to BD, and that the end A has a velocity in the direction of and equal to AC. As the whole rod, for the instant, is moving as if it were revolving about a center, the actual velocities of the various points in the rod are proportional to their distances from the center. To find the center for the case shown, draw the lines AT and BT perpendicular to AC and BD, respectively, until they meet at T, which is the center about which the whole rod may be considered to be revolving. The velocities AC and BD cannot be chosen at random, but must be such that BF is equal to AE; that is, their components in the direction of AB must be equal.

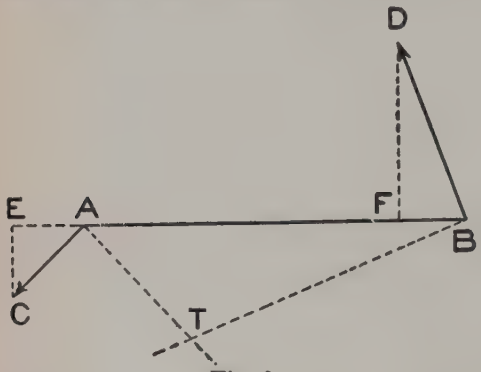


Fig. 6.

REVOLVING BODIES.

One of the most common motions which is found in machinery of all kinds is the motion of revolution, that is, the motion of a

body turning around a center or axis. The axis may pass through the body itself or it may lie entirely outside the body. Fig. 7 is an example of the first case, where the cylinder is revolving about the shaft A, which passes through the center of the cylinder. Fig. 8 is an example of the second case where the block B is revolving about the shaft A.

The speed of revolution of a body is generally described by giving its number of revolutions per minute, which is abbreviated to R. P. M.

We will use the following abbreviations throughout this instruction paper: d=diameter; r=radius or distance of a point from the center about which it is revolving, and π (pronounced Pi)=3.1416.

Let us consider a point C on the circumference of the cylinder in Fig. 7. For every complete revolution of the cylinder the

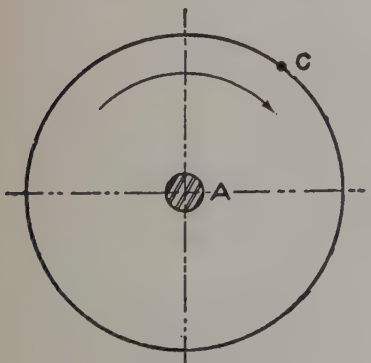


Fig. 7.

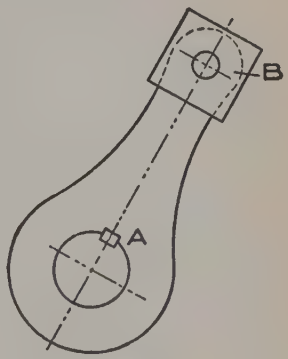


Fig 8.

point C travels through the air a distance equal to the circumference of the cylinder, or, since the circumference of a cylinder is 3.1416 times its diameter, the point C will travel 3.1416 times the diameter of the cylinder. Therefore the actual velocity through the air or **linear velocity** as it is termed, of a point on the circumference of a revolving cylinder is equal to the diameter of cylinder times 3.1416 times the number of revolutions in a unit of time.

If we assume a foot as our unit of distance and a minute as our unit of time, the above principle may be stated as a formula:

$$\text{Linear Velocity} = \pi\, d \text{ times R. P. M.} \qquad (1)$$

$$\text{or} \quad \text{“} \quad \text{“} \quad = 2\,\pi\, r \text{ times R. P. M.} \qquad (2)$$

This will give the linear velocity in feet per minute and to use this formula the diameter or radius must be expressed in feet or fractions of a foot. If d or r is in inches, the linear velocity will be in inches. If linear velocity per second is desired, the number of revolutions per second must be used instead of R. P. M. From this formula we see that the linear velocity varies directly as the diameter or radius, and also directly as the number of revolutions.

The following examples will illustrate the use of the above formula:

If a fly wheel is 10 feet in diameter and makes 75 revolutions per minute, how fast is a point on its circumference moving? Using formula (1),

$$\begin{aligned}\text{Linear Velocity} &= \pi\, d \times \text{R. P. M.} \\ &= 3.1416 \times 10 \times 75. \\ &= 2356.2 \text{ feet per minute.}\end{aligned}$$

Therefore a point on the circumference of the fly wheel is moving at the rate of 2356.2 feet per minute.

Suppose that the center of the block B, Fig. 8, is at a distance of 18 inches from the center of the shaft A and that the arm turns around the shaft 60 times per minute. To find the linear velocity of the center of block B, we must first reduce the 18 inches to feet. Then,

$$\begin{aligned}\text{Linear Velocity} &= 2 \times 3.1416 \times 1.5 \times 60. \\ &= 565.49 \text{ feet per minute.}\end{aligned}$$

The same formula may be used to find the diameter or radius when the linear velocity and revolutions are given, or to find the revolutions when the linear velocity and diameter or radius are given. To do this, substitute the known quantities in the equation and solve by Algebra to find the unknown quantity. Let V = Linear Velocity.

Linear Velocity: $V = \pi d \times \text{R. P. M.}$

Diameter: $d = \dfrac{V}{\pi \times \text{R. P. M.}}$

Revolutions: $\text{R. P. M.} = \dfrac{V}{\pi d.}$

EXAMPLES FOR PRACTICE.

1. Find the linear velocity of a point on the rim of a fly wheel making 120 revolutions per minute. Assume fly wheel to be 7 feet in diameter. Ans. 2638.9 feet.

2. How many turns will a 6-foot wheel make while going one mile?

Ans. 280.

3. A locomotive is running at the rate of 40 miles per hour. How many revolutions are the $6\frac{1}{2}$-foot drivers making per minute?

Ans. 172.

4. The drivers of a locomotive are $5\frac{1}{2}$ feet in diameter. The crank pin is twelve inches from the center of the wheel. Find the linear velocity in feet per second of the crank pin if the engine makes 25 miles per hour. Ans. 13.32.

CYLINDERS AND CONES REVOLVING IN CONTACT.

When two cylinders are arranged to revolve upon parallel axes which are at a distance apart just equal to the sum of the radii of the two cylinders, their circumferences will touch along one line, and if both cylinders revolve and we assume that there is no slipping of one surface on the other, the surface velocities of their circumferences must be equal, that is, the linear velocity of any point on the surface of one would be the same as the linear velocity of any point on the surface of the other. Then, if in Fig. 9, we let S equal the surface velocity of the cylinders, C the radius of cylinder A, D the radius of B, M the revolutions per minute of A, and N the revolutions per minute of B, we can obtain the following equations by substituting these values in formula (2):—

$$S = 2 \pi C \times M.$$
$$S = 2 \pi D \times N.$$

and dividing the first by the second we have:

$$\frac{S}{S} = \frac{2\pi C \times M}{2\pi D \times N} \text{ or } 1 = \frac{C M}{D N}$$

therefore $D N = C M$ or $D \times N = C \times M$.

According to ratio and proportion in Algebra,

$$\frac{M}{N} = \frac{D}{C} \qquad (3)$$

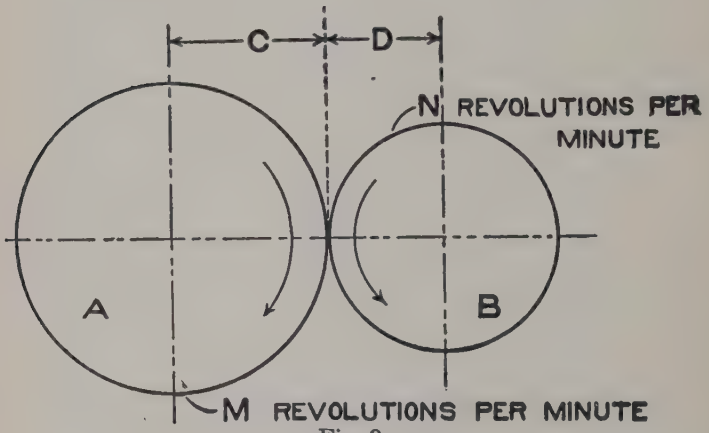


Fig. 9.

This may be stated as follows:—

$$\frac{\text{Revolutions of Driver}}{\text{Revolutions of Driven}} = \frac{\text{Radius of Driven}}{\text{Radius of Driver}}$$

That is, the numbers of revolutions are to each other inversely as the radii, and therefore as the diameters.

Two cylinders revolving in contact, without slipping, revolve in opposite directions; that is, if A revolves right-handed (like the hands of a clock), B will revolve left-handed. This is indicated by the arrows in Fig. 9.

The following examples will illustrate the method of calculation for speeds of cylinders, according to the preceeding discussion. Suppose a wheel A, 2 feet in diameter, is revolving with its surface in contact with the surface of another wheel B. A makes

25 R. P. M. Assuming that no slipping occurs between the surfaces of the two wheels, what must be the diameter of B in order that it shall make 75 R. P. M.? From the formula (3) we have

$$\frac{\text{Diameter of B}}{\text{Diameter of A}} = \frac{\text{R. P. M. of A}}{\text{R. P. M. of B}}$$

or

$$\frac{\text{Diameter of B}}{2 \text{ feet}} = \frac{25}{75}$$

$$\text{Diameter of B} \times 75 = 2 \times 25$$

therefore Diameter of B $= \frac{2}{3}$ feet $= 8$ inches.

The same principles apply to cones which are revolving in contact. Let Fig. 10 represent the side view of two right cones which are in contact along the line EF, which is an element common to both. Then,

$$\frac{\text{R. P. M. of A}}{\text{R. P. M. of B}} = \frac{\text{F G}}{\text{F H}} \qquad (4$$

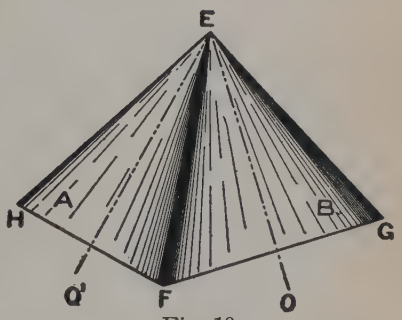


Fig. 10.

That is, their revolutions are to each other inversely as the diameters of their bases. If the angles OEF and O'EF are known, instead of the diameters of the bases, the ratio of the number of revolutions may be found from the following trigonometric formula:

$$\frac{\text{R. P. M. of A}}{\text{R. P. M. of B}} = \frac{\text{Sine of angle OEF}}{\text{Sine of angle O'EF}} \qquad (5)$$

If the angle between the axes OE and O'E is given and it is desired to find the relative sizes of the two cones whose revolutions shall have a given ratio, the angles OEF and O'EF could be calculated, but the calculation would be rather difficult and therefore a solution which is partly graphical is more convenient and usually sufficiently accurate.

Let EO' and EO Fig. 11, be the center lines of two shafts which lie in the same plane and make an angle of 45 degrees with each other. The shafts are to be connected by two rolling

cones so that the shaft O'E shall make 30 revolutions while the shaft OE makes 40. The base of the larger cone is 12 inches, to find the base of the smaller cone and the altitude of both. Since, from the preceding discussion, the speeds are inversely as the diameters of the cones, the larger cone must be on the shaft which is making the fewer number of revolutions, that is, O'E.

Then from formula (4).

$$\frac{\text{Speed of O'E}}{\text{Speed of O E}} = \frac{\text{Diameter of base of cone on O E}}{\text{Diameter of base of cone on O'E}}$$

$$\frac{3}{4} = \frac{\text{Diameter of base of cone on OE}}{12}$$

Solving the equation we get

Diameter of base of cone OE = 9 inches.

Now draw the line PN parallel to O'E and at a distance from O'E equal to the radius of the base of the cone O'E (in this case 6 inches), at a convenient scale, and draw the line ML parallel to OE and at a distance equal to the radius of the base of the cone on OE (in this case $4\frac{1}{2}$ inches). These lines intersect at the point C. A line from C to E is the element along which the cones touch each other. From C draw lines perpendicular to OE and O'E, meeting them at S and R respectively. Then SE and RE are the altitudes. To draw the cones, lay off ST equal to CS, and RV equal to CR. Join E with T and V and the cones are complete.

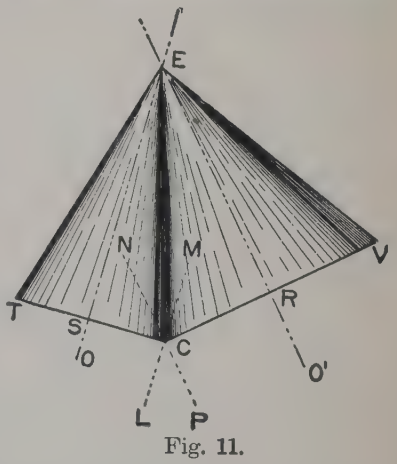


Fig. 11.

CYLINDERS AND CONES CONNECTED BY BELTS.

Frequently two shafts must be connected so that one may drive the other, and yet they are so far apart that cylinders cannot

be placed on them which will touch each other. In this case it is customary to place on each shaft a cylinder, or pulley, and over

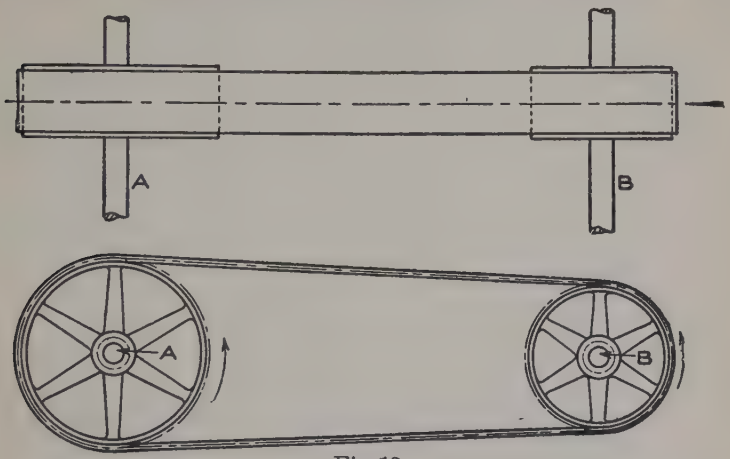


Fig 12.

these pulleys stretch a band, or belt made of some flexible material. The pulleys are fastened to the shafts so that the pulley and its shaft turn together, and the belt is stretched over the pulleys tight enough so that the friction between the belt and the surface

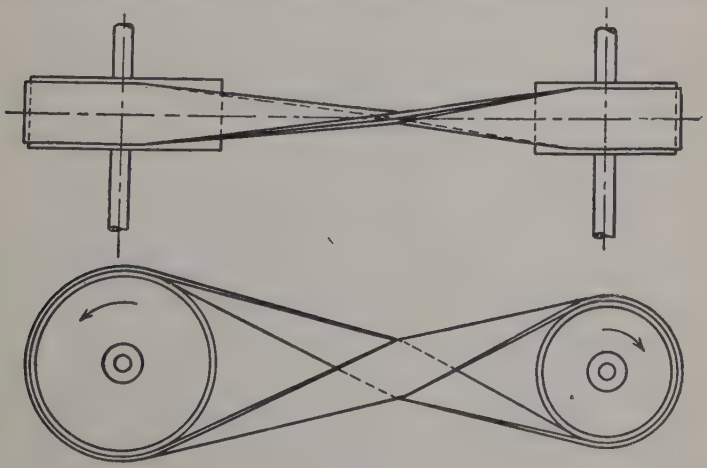


Fig. 13.

of the pulley is sufficient to make them travel with the same linear velocity. A detailed study of the exact manner of finding the proper locations of the pulleys and drawing the pulleys and belts can be found in Mechanical Drawing Part V, so that we will

now study only the general principles involved, particularly with reference to making the necessary calculations.

The principles which we learned above, concerning the relative speeds of two cylinders in contact, apply also to two pulleys connected by a belt. The rule governing the direction of rotation, however, is different. When the connection is made by means of a belt, the relation of the directions of rotation depends upon the way the belt is put around the pulleys. If the belt is put on as shown in Fig. 12, known as open belt, the pulleys will turn in the

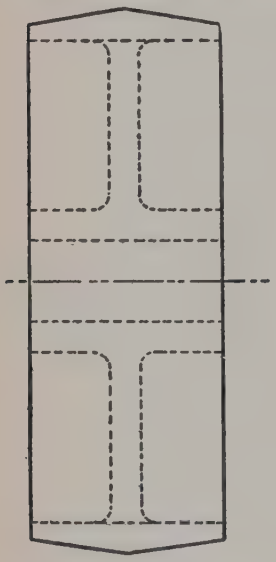


Fig. 14.

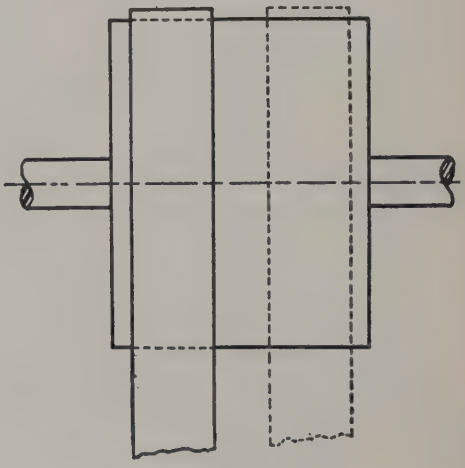


Fig. 15.

same direction. If the belt is as shown in Fig. 13, known as a crossed belt, the pulleys will turn in opposite directions.

Crowning Pulleys. The outer surface of pulleys, instead of being made cylindrical is often made of larger diameter in the middle, as shown in Fig. 14. A pulley having this increase of diameter in the middle is said to have a crowned face. The object of the crowning is to help the belt to remain on the pulley. A belt will always run to the part of the pulley which is largest in diameter; therefore, if the diameter increases towards the middle, the belt will tend to run to the middle, and will be less likely to slip off. If the belt is to be at different places on the pulley at

different times, as indicated by the full and dotted positions in Fig. 15, the surface cannot be crowned, but must be cylindrical.

As problems similar to the following often arise, this one should be studied carefully until every step is understood. In Fig. 16, A is a shaft turning 60 R. P. M. in the direction indicated by the arrow. B and C are cylinders over which a strand of cloth is to pass as indicated, the cloth passing over the top of B and under the bottom of C. In order that B and C may revolve in proper direction a crossed belt must be used between A and C,

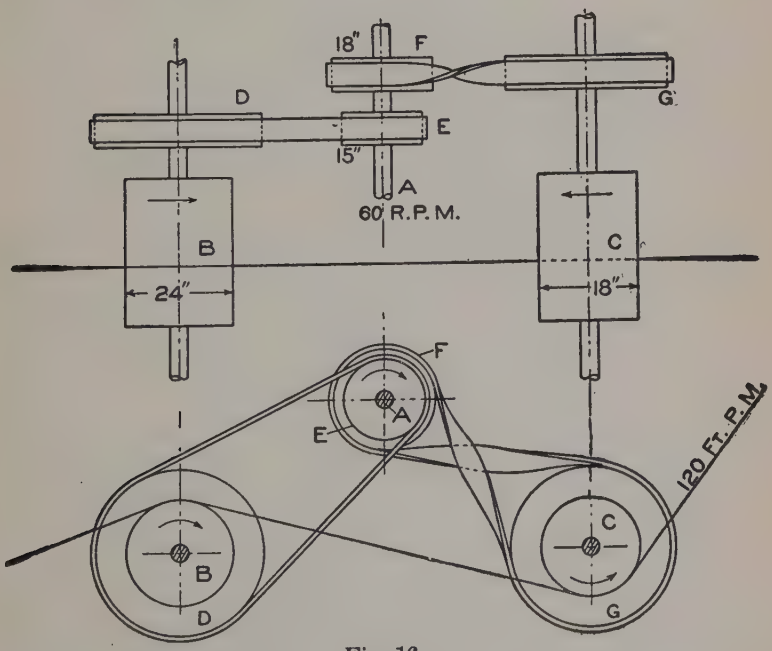


Fig. 16.

as shown. B is 24 inches in diameter, C is 18 inches in diameter, and the cloth is to travel at the rate of 120 feet per minute. E is a pulley 15 inches in diameter, which drives the pulley D, on the same shaft as B. F is a pulley 18 inches in diameter, driving pulley, G, on the same shaft as C. The problem is to find the number of revolutions of B and C, and the diameters of D and G.

The circumference of B = 24 inches $\times \pi$ = 2 feet $\times \pi$ = 6.2832 feet. Therefore, its surface velocity if it made one R. P. M. would be 6.2832 feet per minute. But since it is to have a surface

velocity = 120 feet per minute (equal to that of the cloth) its speed must be 120 divided by 6.2832 = 19.1 R. P. M. Revolutions of C are found in the same way.

18 inches = 1.5 feet. 1.5 feet × 3.1416 = 4.7124 feet = surface speed.

120 divided by 4.7124 = 25.4 R. P. M.

Now from formula (3):

$$\frac{\text{Revs. of D}}{\text{Revs. of E}} = \frac{\text{Diameter of E}}{\text{Diameter of D}}$$

and since the revolutions of D = the revolutions of B

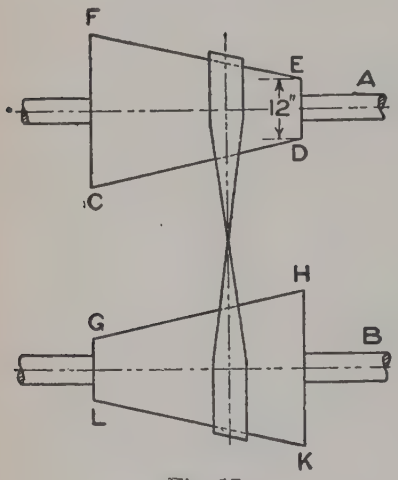


Fig. 17.

$$\frac{19.1}{60} = \frac{15}{x}$$

$$19.1\,x = 15 \times 60$$

$$x = 47.12 +$$

therefore, pulley D is $47\frac{1}{8}$ inches in diameter.

$$\frac{\text{Revs. of G}}{\text{Revs. of F}} = \frac{\text{Diameter of F}}{\text{Diameter of G}}$$

$$\frac{25.4}{60} = \frac{18}{x}$$

$$25.4\,x = 18 \times 60$$

$$x = 42.5 \text{ (approx.)}$$

therefore, pulley G is 42.5 inches in diameter.

Taper Cones. Suppose two equal frustums of cones are arranged on parallel shafts, as shown in Fig. 17. Shaft A, turning at a constant speed, can be made to drive shaft B at different speeds by changing the location of the belt on the cones. In order to use cones with a straight taper, a crossed belt should be used. If an open belt is used, the cones should be shaped as shown in Fig. 18. It is necessary to give this curvature to the face in order to keep the same tension on the belt for different positions. With a crossed belt this condition is fulfilled by making the face a straight line. If the shafts are far apart, the straight cones are sometimes used for an open belt.

Since the calculations for finding the proper shape of the cones for an open belt are difficult and are not often needed, we will give our attention only to the straight cones for a crossed belt.

In Fig. 17 let shaft A be the driver, turning at a constant speed of 100 R. P. M. The small end of the cone on A is 12 inches in diameter. We wish to find the diameter of the large end of the cone on B, in order that the slowest speed of B may be 75 R. P. M. Then, if the cones are alike, to find the greatest speed of B:

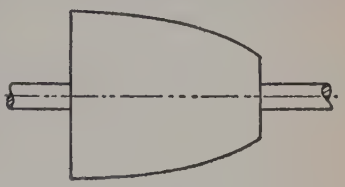


Fig. 18.

First $$\frac{\text{R. P. M. of A}}{\text{R. P. M. of B}} = \frac{\text{H K}}{\text{E D}}$$

$$\frac{100}{75} = \frac{\text{H K}}{12}$$

$$75\ \text{HK} = 12 \times 100$$

Therefore $$\text{H K} = \frac{1200}{75} = 16 \text{ inches.}$$

Now, if the cones are equal

and $$\text{G L} = \text{E D} = 12$$
$$\text{F C} = \text{H K} = 16.$$

Then $$\frac{\text{R. P. M. of A}}{\text{R. P. M. of B}} = \frac{\text{G L}}{\text{F C}}$$

$$\frac{100}{x} = \frac{12}{16}$$

$$x = \frac{1600}{12} = 133\tfrac{1}{3}.$$

Therefore, the larger ends of the cones must be 16 inches in diameter and B will have a variation of speed from 75 R. P. M. to $133\frac{1}{3}$ R. P. M. The length of the cone does not affect the extreme speeds, but the longer the cones the more easily the intermediate speeds may be obtained.

Cones arranged as explained above are used to drive drying machines in bleacheries and similar places, where it is desired to vary the speed af the machine according to the weight of the cloth which is being dried. Heavy cloth requires a longer time to dry than light cloth and consequently can not be passed through the

machine as rapidly. Tapered cones are also found in various cotton machines.

Stepped Cones. Stepped cones are often used in place of the tapered cones. These are really a series of pulleys side by side on a shaft, a similar series being placed on the other shaft with the large pulley on the second shaft in line with the small pulley on the first shaft. The arrangement is shown in Fig. 19. In practice the several pulleys which make up the stepped cones are cast together, both cones usually being cast from one pattern. The cal-

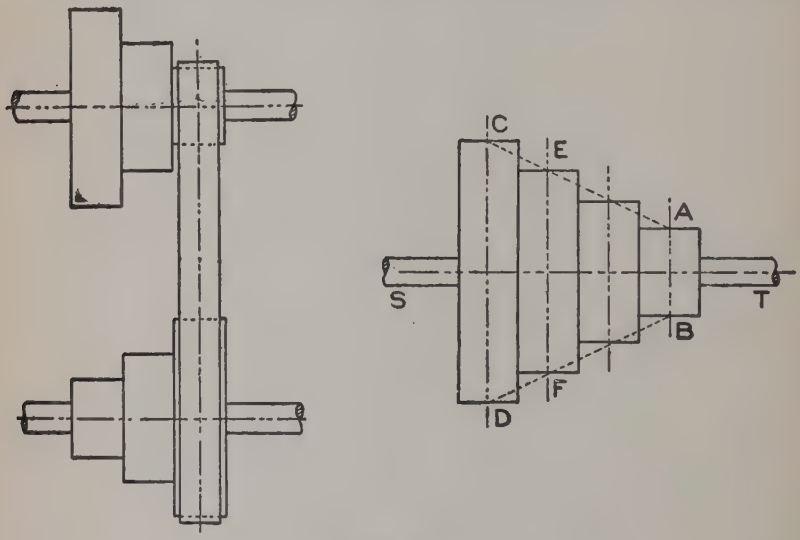


Fig. 19.

culation for the diameters of the end steps are the same as for the end diameters for the cones (Fig. 17). Assuming that both cones are alike, the intermediate steps can be found as follows:—

Decide how many intermediate steps are desired, then draw the center line ST, and draw the lines AB and CD perpendicular to ST and at a distance apart equal to the width of the face of one step multiplied by the whole number of steps minus one. Make CD equal in length to the diameter of the largest step and AB equal to the diameter of the smallest step. Draw AC and BD. Draw EF parallel to and at a distance from CD equal to the width of the face of one step. The distance between E and F, the points where EF intersects AC and BD, will be the diameter of the sec-

ond step. Other steps may be found in the same manner. To use this method all steps must have the same width of face. It would not be accurate for an open belt (since the angle of contact varies), although if the distance between the shafts are large compared with the diameter of the cones, an open belt might not give trouble on cones designed in this way. Stepped cones are very commonly used for driving lathes and other machine tools.

EXAMPLES FOR PRACTICE.

1. A shaft making 115 revolutions per minute has keyed to it a pulley 36 inches in diameter. If the pulley belted to the 36-inch pulley is 26 inches in diameter, how many revolutions will it make per minute?

Ans. 160 revolutions. (nearly.)

2. A pulley 12 inches in diameter makes 180 revolutions per minute. The other pulley connected by belt to the 12-inch pulley should make 75 revolutions. How large must it be?

Ans. 28.8 inches in diameter.

3. A motor shaft having a pulley 6 inches in diameter makes 840 revolutions. If this speed is to be reduced to 320 revolutions, what size pulley should be used?

Ans. $15\frac{3}{4}$ inches in diameter.

Disk and Roller. Fig. 20 shows a device by means of which one shaft turning always in the same direction with a constant speed may drive another shaft, which is at right angles to it, in either direction and at different speeds. A is a disk on the end of the overhanging shaft S. On the shaft T is placed a roller B free to be moved up or down on T, but on a key so that it must turn with the shaft. Some sort of a shipper must be provided to hold B in the desired position on T. When one shaft turns it drives the other by means of the friction between A and B. If shaft S is the driver, turning in the direction indicated by the arrow, it will cause T to turn in the direction indicated by the lower arrow. If it is desired to have T turn in the opposite direction, keeping the direction of S the same, B must be moved up above the center line of S as shown dotted. If OR is the distance from the center of disk A to the point where the center line of the face of B strikes

A, and LR is the radius of B, we have the following equation,—

$$\frac{\text{R. P. M. of B}}{\text{R. P. M. of A}} = \frac{\text{O R}}{\text{L R}} \qquad (6)$$

from which, knowing the speed of one, the speed of the other may be calculated. It will be seen from this equation that if OR is decreased, that is, if B is moved nearer the center line of S, the speed of B will decrease if A is the driver, or the speed of A will increase if B is the driver.

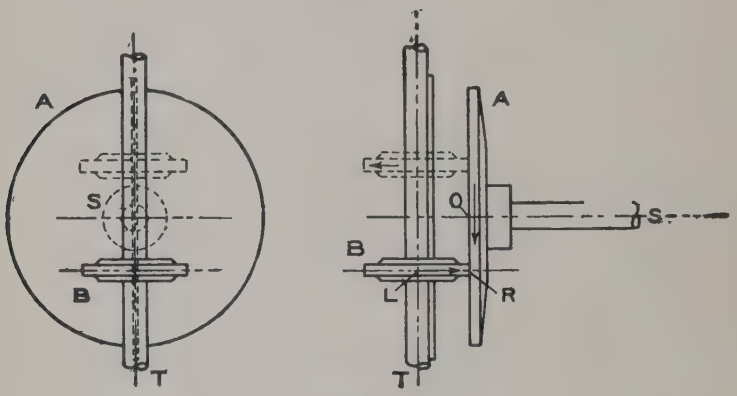


Fig. 20.

This device is used for driving drying machines where the cloth goes from another machine direct to the drying machine, and it is essential that the speed of the two should be adjusted to a nicety, in order that excessive strain may not come upon the cloth. It is also used for driving the feed mechanism on machine tools, particularly drills.

Example: Suppose the disk A makes 70 revolutions per minute and disk B 124 revolutions. If OR is 18 inches what is the diameter of B?

$$\frac{\text{R. P. M. of B}}{\text{R. P. M. of A}} = \frac{\text{O R}}{\text{L R}} \text{ or } \frac{124}{70} = \frac{18}{\text{L R}}$$

$$124 \times \text{L R} = 70 \times 18$$

$$\text{L R} = \frac{70 \times 18}{124}$$

$$= 10.16 \text{ inches (about).}$$

Diameter would be $2 \times 10.16 = 20.32$ inches or $20\frac{5}{16}$ inches.

EXAMPLE FOR PRACTICE.

1. Disc B, Fig. 20, is 12 inches in diameter and makes 280 revolutions per minute. If shaft S is to make 48 revolutions per minute how far from the center must the circumference of B be placed? Ans. 35 inches.

DISCONNECTING AND REVERSING MECHANISMS.

Tight and Loose Pulleys. Fig. 21 shows a very common arrangement of pulleys, whereby the shaft A may be stopped while the driving shaft B continues to run. Pulley C is keyed to

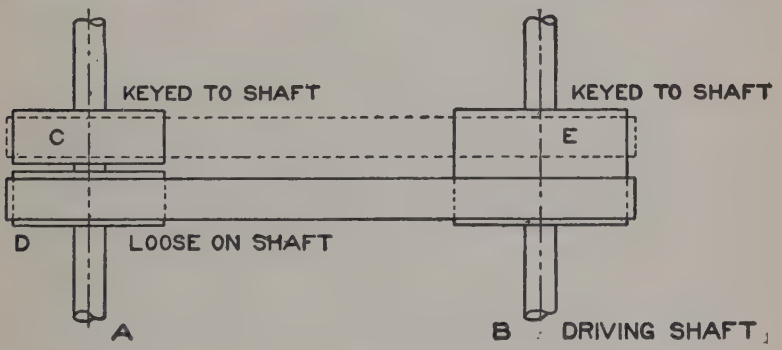


Fig. 21.

shaft A, while pulley D is free to run on A. Pulley E has its face equal in width to the sum of the other two and is keyed to B. When the belt is in the position shown in full lines, D turns with E, while shaft A remains at rest. The belt is guided by a shipper and when it is desired to start A, the belt is moved into the position shown by the dotted lines.

Jaw Clutch. Fig. 22 illustrates an arrangement by which the gear, or pulley, A may be attached to turn with the shaft, or disconnected so as to turn independently of the shaft. The hub of A has jaws or teeth on its end, and the sliding piece B has similar teeth, the projections on B fitting into the indentations of A. The shaft may turn freely in A while B slides on a key so that it must turn with the shaft. When B is in the position shown, the shaft and A may turn independently of each other, but when B is

moved to the left so that its teeth engage with the teeth on the hub of A, it serves to clamp A to the shaft. The principle here involved is used in many different forms of clutches.

Friction Clutches. A jaw clutch such as illustrated in Fig. 22, if thrown in while the shaft or gear is turning brings a sudden shock on the parts, which is likely to cause damage, especially if the speed is high and much power is transmitted. Consequently, a clutch known as a friction clutch is often used, which, as its action depends upon the friction between two parts, will impart motion more gradually thereby avoiding the shock. Fig. 23 illus-

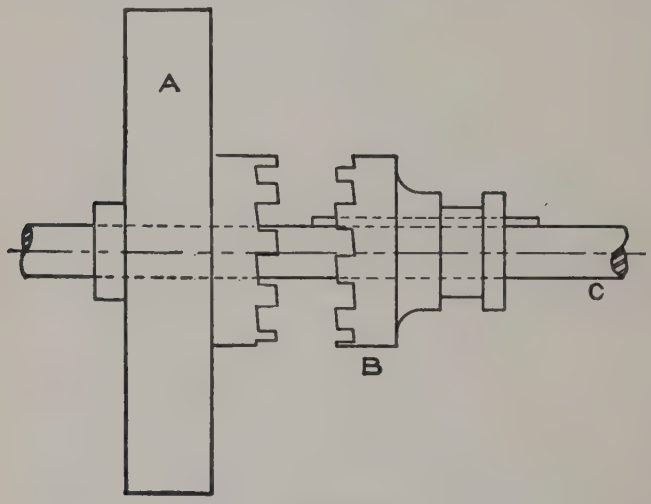


Fig. 22.

trates a simple clutch of this kind. B is a piece free to slide on a key, and held in position by a shipper. A is a pulley or gear loose on the shaft. The outer surface of B and the inner surface of A are tapered to fit each other. When B is thrown to the left it clamps A to the shaft in the same manner as the jaw clutch.

Two Clutches for Reversing. Fig. 24 shows how two clutches can be arranged so that either one may be thrown in, thus giving motion to the shaft in either direction. The clutches are similar in principle to the one shown in Fig. 23. The left-hand clutch is shown partly cross-sectioned. The piece A is attached to a shipper which when moved to the right throws in the right-hand clutch; when moved to the left throws in the left-hand clutch. If the pul-

ley of the right-hand clutch is driven by an open belt and the pulley of the left-hand clutch by a crossed belt, the shaft will be driven

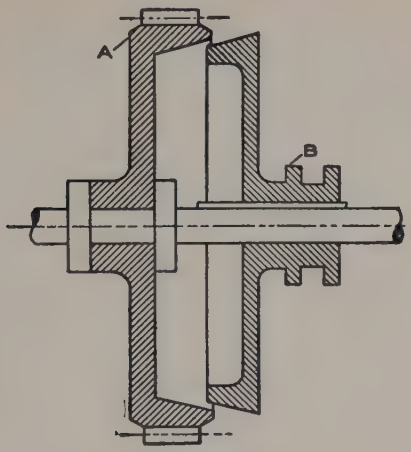


Fig. 23.

in either direction according as one or the other clutch is thrown in. When A is in the position shown neither clutch is in and the shaft is at rest.

SCREWS.

The Helix. Since all screws depend upon a curve known as

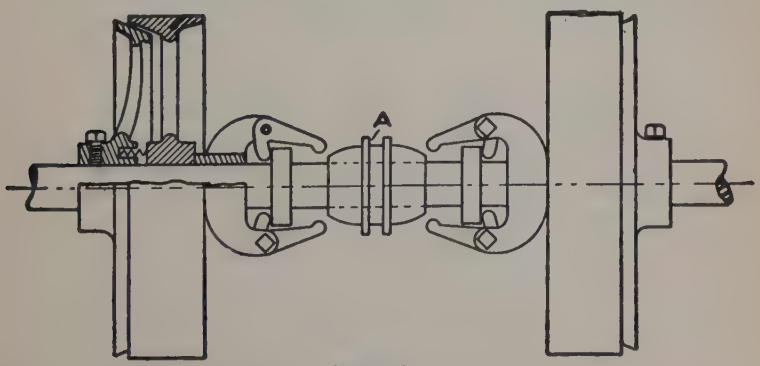


Fig. 24.

the helix, it will be necessary to understand something about this curve before attempting the study of the screw.

Take a cylindrical piece of wood, such as is shown in Fig. 25, and a rectangular piece of paper, ABFE, with the side AB equal

to the circumference of the cylinder, and the side AE equal to the length of the cylinder. Now, if we lay off along AE a distance

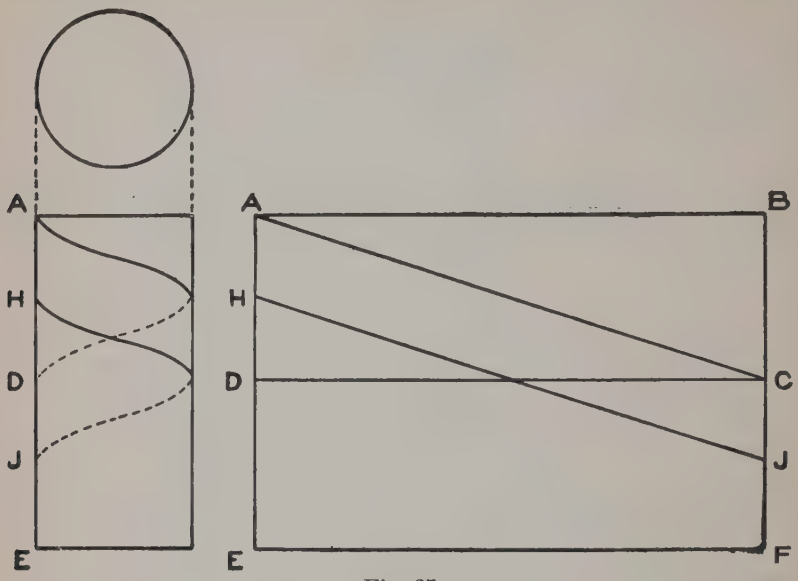


Fig. 25.

AD, and draw the line DC parallel to AB, we have the rectangle, ABCD. Now draw the diagonal, AC, of the rectangle and wrap the paper around the cylinder, keeping the side AE on an element of the cylinder; the paper will just cover the cylinder, the edge

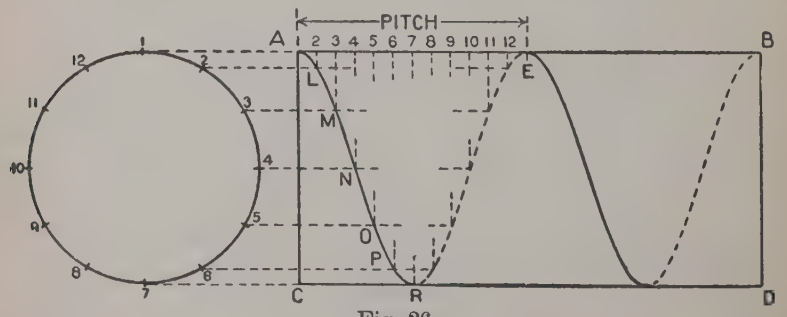


Fig. 26.

BF meeting the edge AE. The point C will coincide with D and lie on the same element of the cylinder as A and at a distance from A equal to AD. The shape which the line AC now takes is called a helix, and the distance AD is called the pitch of the helix. If

we choose another point, H, half-way between A and D, and draw a line HJ parallel to AC, this line when wrapped around the cylinder will form another helix of the same pitch as the first one. The two together form what may be called a double helix. If the line AD is divided into three equal parts instead of two, and lines

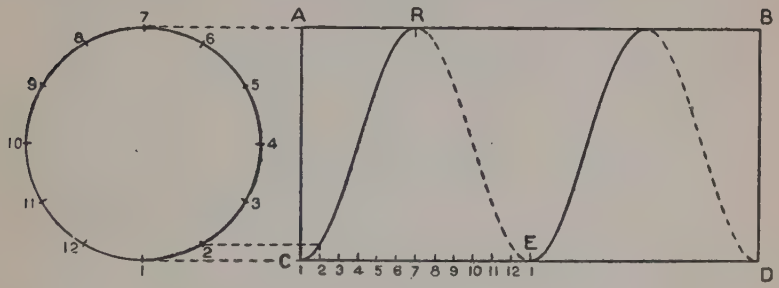


Fig. 27.

parallel to AC be drawn from each of the points of division, we would have on the cylinder three parallel and equidistant helices of the same pitch, or a triple helix. Fig. 26 shows a single right-hand helix, Fig. 27 a single left-hand helix, Fig. 28 a double right-hand helix, and Fig. 29 a triple right-hand helix.

If a helical groove is cut on the surface of a cylinder, a screw

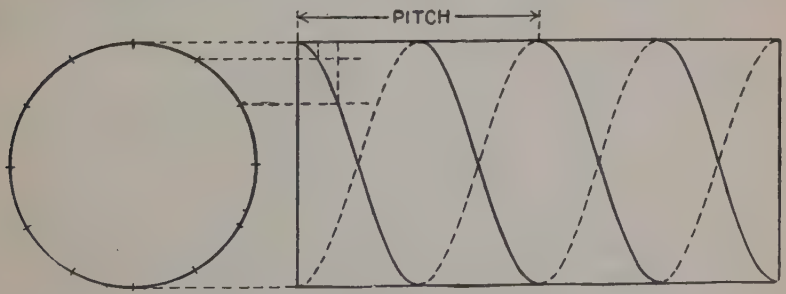


Fig. 28.

thread is formed, the thread being the material which is left between the successive turns of the helical groove. A cylinder having a thread on it is called a screw, and a piece having a cylindrical hole in it, with a thread around the hole, is called a nut. The groove which is cut to form the thread may be in the form of a single, double or triple helix, and either right-hand or left-hand; the thread would be described in the same terms.

Fig. 30 shows a right-hand and a left-hand single V thread and a right-hand and a left-hand single square thread.

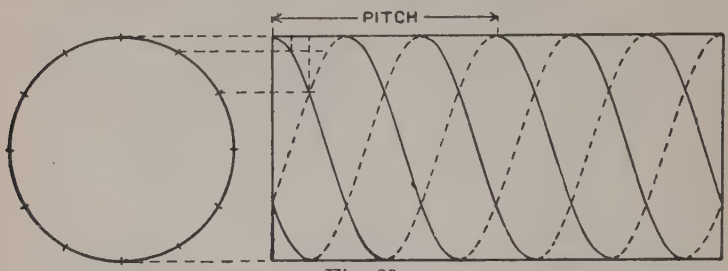


Fig. 29.

One complete turn of a screw causes it to travel through its nut a distance equal to its pitch.

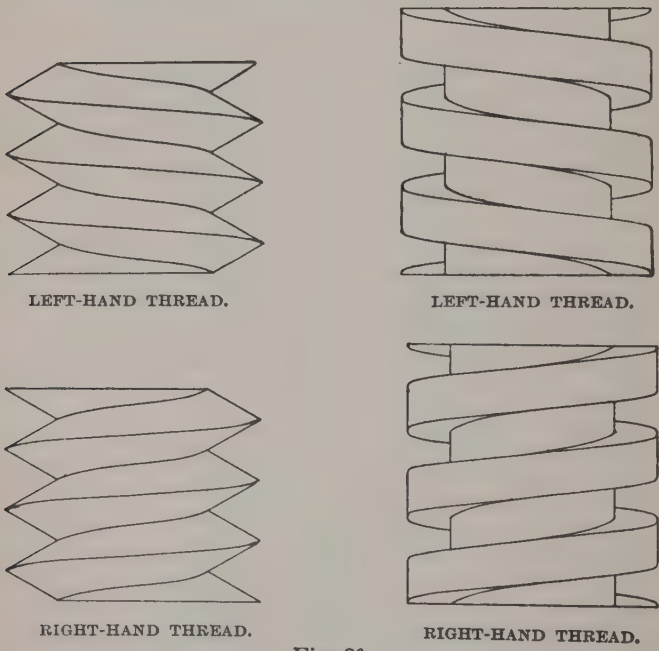


Fig. 30.

There are certain principles which apply and certain problems which arise, in connection with all forms of screws, and we shall now consider some of the most important of these.

Let Fig. 31 represent a jack screw. The pitch of the screw is P inches; the length of the bar from the axis of the screw to

the point R, where the force is applied, is A inches. A force of F pounds is exerted at R, raising the weight W.

The following equation holds true,

$$\frac{F}{W} = \frac{\text{Distance W moves}}{\text{Distance F moves}} \qquad (7)$$

Suppose the screw to be turned once; then F will move through a distance approximately equal to the circumference of a circle whose radius is A; that is, F moves a distance $2\pi A$. In turning the screw once, W is raised a distance P. Then, substituting, in equation (7), these quantities for the distances which F and W respectively move, we get

$$(8)\quad \frac{F}{W} = \frac{P}{2\pi A} \qquad \text{or}$$

$$2\pi A F = W \times P$$

$$W \times P = 2\pi A \times F$$

From this equation, if any three of the quantities F, W, P or A are known, the fourth may be found. P and A must both be expressed in feet or both in inches.

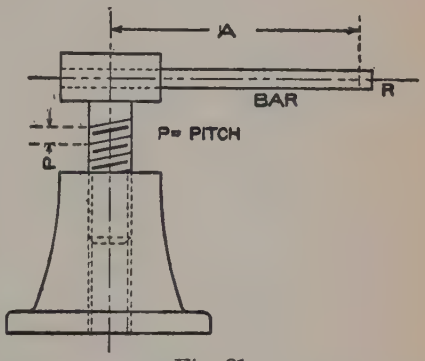


Fig. 31.

For example, let $P = \frac{1}{4}$ inch, A = 5 feet, F = 100 pounds. Substituting in the formule we get

$$\frac{100}{W} = \frac{.25}{2 \times 3.1416 \times 60}$$

$$.25\ W = 37699.2$$

$$W = 150{,}797 \text{ pounds (nearly).}$$

EXAMPLES FOR PRACTICE.

1. Suppose a weight of 200,000 pounds is to be raised by a jack screw. The pitch is .20 inch, and the force applied is 125 pounds. What must be the length of the bar?

Ans. 51 inches (nearly).

2. What should be the pitch of the screw of example 1 if the bar is made 6 feet long? Ans. .28+ inches.

3. A jack screw has the following dimensions: Length of arm, $5\frac{1}{2}$ feet; pitch, .125 inch. If 200,000 pounds are to be raised what force must be applied at the end of the bar?

Ans. 60 pounds.

Combination of Screws. Fig. 32 illustrates a method by which the space moved through by the nut C may be made very small in comparison with the space moved through by a point on the circumference of the hand wheel, without using a very fine pitch on the screw. Great pressure can thus be produced at C by a small force on the wheel, without danger of stripping the thread, which might occur if the screw had a fine pitch. The upper part of the screw E has a coarse thread which acts in the nut B, this nut being rigid with the frame D. The lower part of the screw has a pitch different from the upper part and acts in the nut C. C is free to slide up or down in the frame, but is prevented from turning by the lips L.

Let P = the pitch of the upper part of the screw and p = the pitch of the lower part, both threads being right-hand, and P being greater than p. If the screw were attached to C by a collar instead of being threaded into it, one turn of the screw right-handed in nut B would cause the screw to advance a distance P, carrying C forward the same distance. But since by the same turn the screw has drawn nut C on to itself a distance p, the actual distance, K, which C has advanced is

$$K = P - p \qquad (9)$$

If p were greater than P, K would have a minus value; that is, C would actually move up for a right-handed turn of the screw. If one of the screws is left-handed and the other right-handed, the equation would become

$$K = P + p. \qquad (10)$$

Let P = $\frac{1}{4}$ inch and $p = \frac{3}{16}$ inch, and let both screws be right-handed. If the radius A of the hand wheel is 12 inches, how much pressure can be exerted at C by a force of 50 pounds, applied to the circumference of the wheel?

The same principle holds here as in the case of a simple screw; that is, the forces exerted are inversely as the distances moved through, or,

$$\frac{\text{Force at wheel}}{\text{Force at C}} = \frac{\text{Travel of C}}{\text{Travel of point on circum. of wheel}} \quad \text{(11)}$$

so that we must first find the distance C moves for one turn of the wheel. Substituting the values of P and p in formula (9), we get

$K = \frac{1}{4} - \frac{3}{16} = \frac{1}{16}$ = distance C moves for one turn of the screw.

The distance which a point on circumference of wheel moves

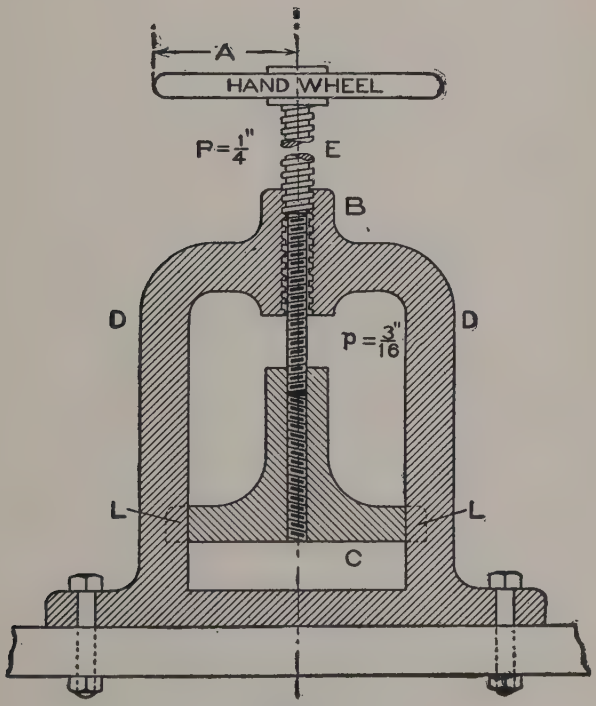


Fig. 32.

$= 2\pi A = 2 \times 3.1416 \times 12 = 75.4$ inches. Substituting these values in formula (11) we get

$$\frac{50}{\text{Force at C}} = \frac{\frac{1}{16}}{75.4}$$

Solving, we get, force at C = 60,320 pounds.

EXAMPLE FOR PRACTICE.

1. Suppose the press shown in Fig. 32 has the following dimensions: P = $\frac{1}{8}$ inch, $p = \frac{1}{6}$ inch, and the force at C is to be 78,000 pounds. What force must be applied to the circumference of the wheel if it is 14 inches in diameter?

Ans. 60 pounds (nearly).

Worm and Wheel. The mechanism known as worm and wheel consists of a wheel, as A, Fig. 33, having teeth on its circumference, and a screw or worm W, meshing with the teeth on the wheel. The axis on which the wheel is fixed is usually at right angles to the axis of the worm. If the worm is turned, the action between it and the teeth on the wheel is similar to the action between a screw and the thread in a nut, so that the wheel will turn also. If the worm is single-threaded, one turn of the worm will cause the wheel to advance one tooth, so that in order for the wheel to make one complete revolution, as many turns of the worm will be required as there are teeth in the wheel. If the worm is double-threaded, half as many turns will be required as there are teeth in the wheel; if the worm is triple-threaded, one-third as many turns will be required as there are teeth in the wheel.

Suppose the worm be single-threaded and turned by a crank whose length is R; let the worm wheel have n teeth and have on its shaft a cylinder of radius K, with a cord wound around it supporting the weight L. If a force of F pounds is applied to the crank, the same principle holds true as in the other mechanisms which we have studied, namely,

$$\frac{F}{L} = \frac{\text{Distance L moves}}{\text{Distance F moves}} \qquad (12)$$

If the worm makes one revolution, F will move through a distance $2\pi R$. The wheel makes $\frac{1}{n}$ revolutions, and consequently the cylinder to which L is attached will make $\frac{1}{n}$ revolutions. If the cylinder made a whole revolution it would raise L a distance equal to its circumference $= 2\pi K$, therefore, when it makes one revolution it will raise L a distance $\frac{2\pi K}{n}$. Substituting this value for the distance L moves, in formula (12), and substituting for distance F moves, the quantity $2\pi R$, we get

$$\frac{F}{L} = \frac{\frac{2\pi K}{n}}{2\pi R} = \frac{2\pi K}{2\pi nR}$$

Therefore,

$$\frac{F}{L} = \frac{K}{nR} \qquad (13)$$

If the worm is double-threaded, L will be raised twice as far for one turn of the worm, so that the above formula would become for a double threaded worm and wheel,

$$\frac{F}{L} = \frac{2K}{nR} \qquad (14)$$

and for a triple-threaded worm and wheel,

$$\frac{F}{L} = \frac{3K}{nR} \qquad (15)$$

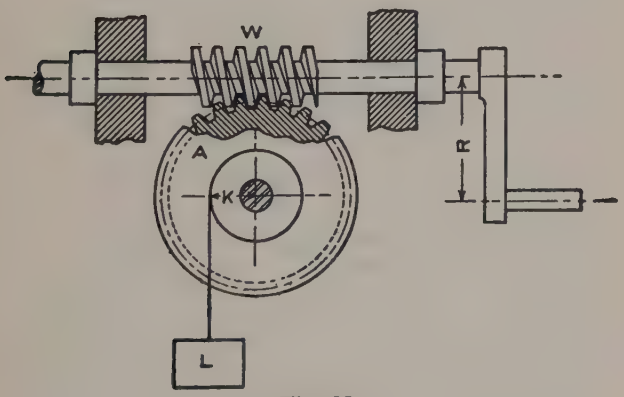


Fig. 33.

For example, a single-threaded worm makes 180 revolutions per minute and the worm wheel has 30 teeth, how many feet per minute will a weight be raised if the cylinder on the shaft of the worm wheel is 12 inches in diameter?

For each revolution of the worm wheel the worm must make 30 revolutions, hence the worm wheel makes 6 revolutions per minute. The circumference of the cylinder is $2\pi R$ or $2 \times 3.1416 \times 6 = 37.699$ inches and $6 \times 37.699 = 226.197$ inches $= 18.85$ feet.

EXAMPLES FOR PRACTICE.

1. A crank of 18 inches radius is attached to a worm of a single thread. The worm wheel has 48 teeth and is attached to a drum 14 inches in diameter. What weight can be raised if 80 pounds is applied to the crank?

Ans. $9874\frac{2}{7}$ pounds.

2. If the crank in above device is given 216 revolutions per minute how fast will the weight rise?

Ans. $16\frac{1}{2}$ feet (nearly).

3. How fast would it rise if the worm has a double thread?

Answer 33 feet.

CAMS.

A cam is a plate or cylinder having a curved outline, or a curved groove in it, which, by its rotation about a fixed axis, imparts a backward and forward motion to a piece in contact with it. The motion imparted to the follower may be at right angles to or parallel with the axis of the cam, or at some other angle.

The motions which cams are designed to give to their followers commonly belonged to one of the following kinds: uniform motion, harmonic motion, or "gravity" motion. The cam may give one kind of motion all the time or it may give different kinds of motion at different stages in its revolution.

Before studying the cams themselves, we will consider the three kinds of motions mentioned.

Uniform Motion. If a body moves through equal spaces in equal intervals of time, it is said to have uniform motion, that is, its velocity is constant.

Harmonic Motion. If a point as C, Fig. 34, travels around the circumference of a circle with uniform velocity, and another point, as E, travels across the diameter at the same time at such a velocity that it is always at the point where a perpendicular let fall from C would meet the diameter, the point E would be said to have harmonic motion. Its velocity will increase from the starting point A until it reaches the center O, and from O to D its velocity gradually decereases to zero at D.

Gravity Motion, or uniformly accelerated and retarded motion, is also a motion where the velocity gradually increases until it reaches a maximum at the middle of the path and from there

gradually decreases to the end. The rate of increase and decrease, however, is different from that in harmonic motion, the velocity being increased in gravity motion, by equal amounts in equal intervals of time, the spaces traveled over in successive intervals of time being in the ratio of 1, 3, 5, 7, etc., to the middle of the path, and decreasing in the same ratio to the end.

The kind of motion which the follower is desired to have must be taken into consideration when designing a cam.

Plate Cams. Fig. 35 shows a plate cam designed to raise and lower the follower P with uniform motion. The point of P is raised from A to *e* while the cam turns right-handed through two-thirds of a revolution, and is lowered again to its original position during the remaining one-third of a revolution of the cam. In this cam the line of motion to the point of P passes through the point O, which is the center of the shaft on which the cam is fixed.

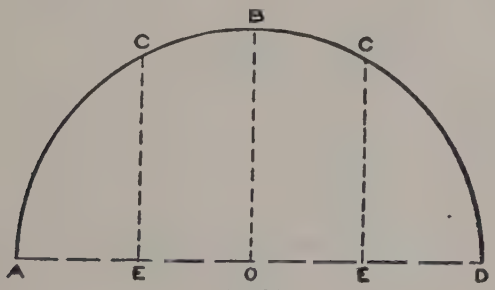


Fig. 34.

To design such a cam, draw a circle with O as a center and passing through A. Since the raising of P is to take place during two-thirds of a revolution, right-handed, find a point E on the circumference of the circle, such that the arc AHE shall be $\frac{2}{3}$ of the whole circumference, thus leaving arc ACE equal to $\frac{1}{3}$ of the circumference. Divide the arc AHE into any number of equal parts and draw the radial lines OF, OG, etc. Divide A*e* into the same number of equal parts and from the points of division 1, 2, 3, etc., thus found, swing arcs around the center O, cutting OF, OG, etc., at points *f*, *g*, etc., respectively. A smooth curve drawn through A, *f*, *g*, etc., to *m*, will give the outline of that part of the cam which raises P. The outline of the rest of the cam is found in a similar manner, by dividing arc ACE into any number of equal

parts and making a new division of Ae into the same number of equal parts, (points d, c, b.)

Fig. 36 shows a cam which gives the same motion to the follower as was given by the cam shown in Fig. 35, but in this case the line of motion of P, instead of passing through O, passes a distance Oa to one side of O. The only difference in the method of designing this cam from that previously described is that instead of drawing radial lines through points A, F, G, etc., we draw lines

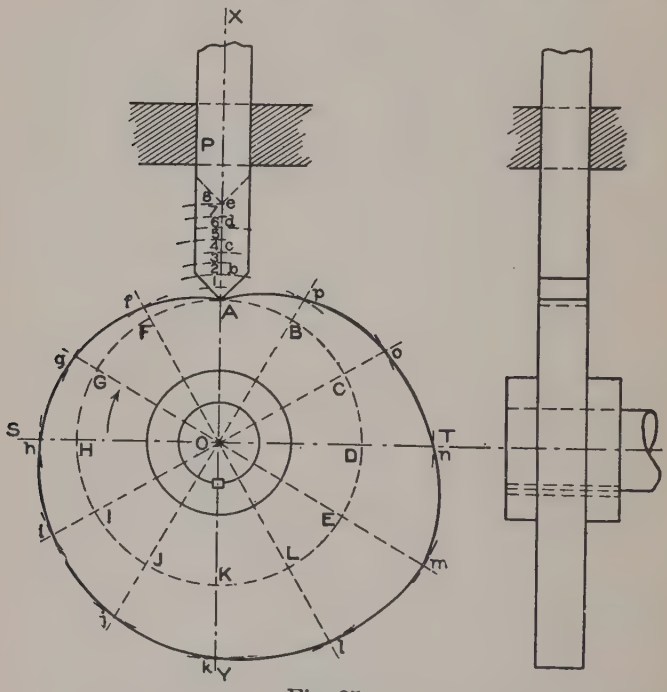


Fig. 35.

through these points tangent to a circle drawn with center O and radius Oa.

If in Figs. 35 and 36 it had been required to raise P with harmonic motion instead of uniform motion, the only difference in construction would have been in making the divisions of Ae. These divisions, instead of being equal, would be found as shown on a larger scale in Fig. 37. On the line Ae as a diameter, draw a semicircle and divide this semicircle into as many equal parts as we divided the arc AHE in Figs. 35 and 36. From the points

BCD, etc. (Fig. 37), draw perpendiculars to line A*e*, cutting it at points 1, 2, 3, etc. The division A – 1, 1 – 2, etc., thus found, are the divisions of A*e* which would be used in finding the cam outline, in place of the equal divisions which were used for uniform motion.

Fig. 38 shows how A*e* would be divided if the motion were

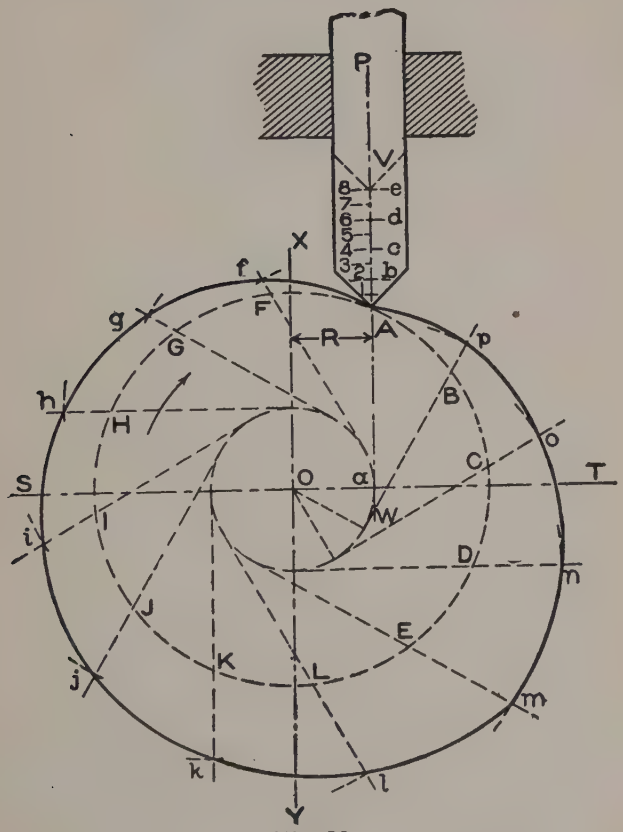


Fig. 36.

to be "Gravity." Since A*e* is to be divided into as many equal parts as arc AHE, in this case it will be divided into eight parts. Now if the motion which the cam is to give to piece P is to be uniformly accelerated and retarded (that is, gravity motion), A*e* must be divided in such a way that the distance from 1 to 2 is three times the distance from A to 1; the distance from 2 to 3 is five times the distance from A to 1; 3 to 4 is seven times A to

1; 4 to 5 is seven times A to 1; 5 to 6 is five times A to 1; 6 to 7 is three times A to 1; and 7 to e is equal to A to 1. Therefore the whole line Ae is $1+3+5+7+7+5+3+1$ or 32 times the distance from A to 1, or in other words, A$-$1 is $\frac{1}{32}$ of the whole line Ae, and 1$-$2 is $\frac{3}{32}$ of Ae, and so on. To divide Ae so that the divisions may bear this relation to each other, draw the line AR at any convenient angle, and choosing any convenient distance as a unit, mark it off on AR thirty-two times, beginning at A. From I, the last of these dividing points, draw a line to e; next find the points B, C, D, etc., as follows: B is the first division from A, C the third from B, etc., thus getting the divisions of A1 in the ratio 1, 3, 5, 7, 7, 5, 3, 1. From the points B, C, D,

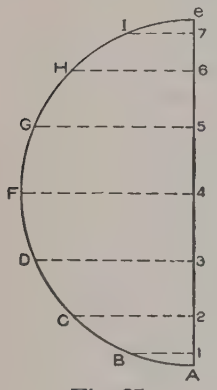


Fig. 37.

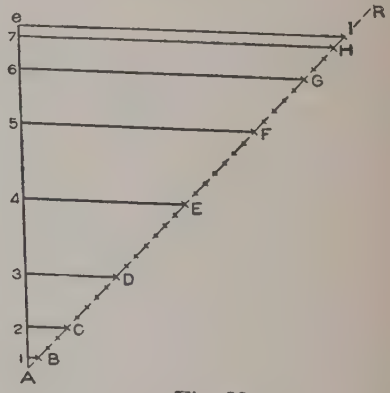


Fig. 38.

etc., draw lines parallel to 1e, meeting Ae at 1, 2, 3, etc., which will be the required points of division.

The cams which we have been considering all act on the comparatively sharp end of the piece P, and consequently much friction and rapid wearing will result if much power is transmitted. Fig. 39 shows a cam designed to act on a roller. The outline is first found for a cam to act on a piece like those in the preceding cases, with its point at the center of the roller. This curve is shown dotted in the figure. Next, with a radius equal to the radius of the roller, and with centers at any number of points around the dotted curve, draw arcs as shown. A smooth curve drawn *tangent* to these arcs will be the outline of the cam which is to act on the roller.

Cylindrical Cams. A plate cam, such as we have been considering, can be designed to give almost any kind of motion in a plane at right angles to the axis of the shaft on which the cam is located, but can not give motion parallel to the axis of the shaft. If, however, we place on the shaft a cylinder with a groove cut in it, the shape of the groove may be made such as to give to a piece inserted in it almost any motion along the shaft; or, if the depth of the groove be varied, the follower may be given a motion which shall be made up of two components, one along the shaft and one at right angles to the shaft.

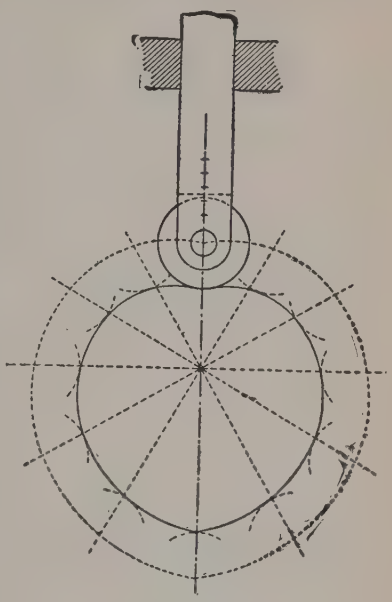


Fig. 39.

Fig. 40 shows two views of a cam designed to give a backward and forward motion in a line parallel to the axis of the shaft.

Familiar illustrations of the use of plate cams are found in the bobbin-winding mechanism on some sewing machines; on

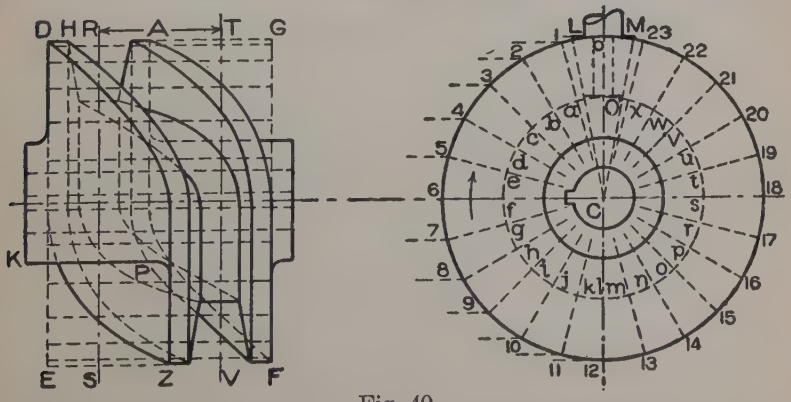


Fig. 40.

many kinds of looms, and in the valve gear on the Brown and other steam engines. Cylindrical cams are used in many places

in textile work and in machine tools. One very common use is in stretchers on many forms of cloth-finishing machinery.

LEVERS.

A lever is a rigid piece supported at some point called the fulcrum, and so arranged that when force is applied at a certain point in the piece, work is done at a certain other point by reason

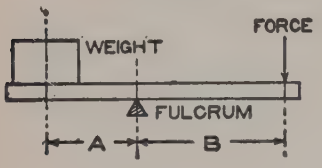


Fig. 41.

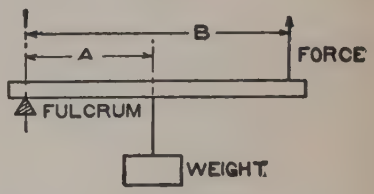


Fig. 42.

of the pivoting action around the fulcrum. Figs. 41, 42 and 43 illustrate the three common kinds of levers, the difference consisting in the relative positions of the force applied and the weight lifted, with respect to the fulcrum. In any of the three cases, if we let F = force applied, W = weight lifted, A = distance from fulcrum to weight, and B = distance from fulcrum to F, we have the following equation:

$$F \times B = A \times W \text{ or}$$

$$\frac{F}{W} = \frac{A}{B} \tag{16}$$

from which, if any three of the quantities are known, the fourth may be found.

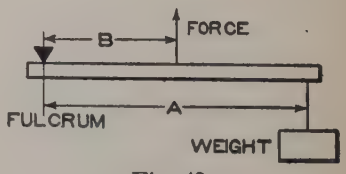


Fig. 43.

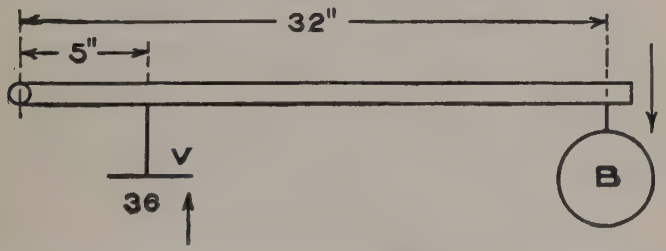
Distance A is called the *weight arm*, and distance B is called the *power arm*. The product of A times the weight is called the moment of the weight, and the product of B times the force is called the moment of the force. Another way of stating the principle expressed in equation (16) is:

Moment of force = moment of weight.

Example: Suppose a weight of 40 pounds is hung on the end of a lever. If the distance from the fulcrum to the weight is 14 inches, what power must be applied to raise the weight, the distance from the fulcrum to the power being 18 inches?

$$F \times B = A \times W$$
$$F \times 18 = 14 \times 40$$
$$F = \frac{14 \times 40}{18}$$
$$= 31.11 \text{ pounds.}$$

Another example: Let the accompanying diagram represent a safety valve. We will neglect the weight of the lever and valve. Suppose the valve V has an area of 3 square inches and the steam pressure per square inch is 36 pounds. The valve is 5 inches from the fulcrum and the weightis 32 inches from the fulcrum. What should be the weight of the ball B?



First, let us find the moment of power. The total upward pressure is $3 \times 36 = 108$, because the total steam pressure equals the pressure per square inch multiplied by the area.

The moment of power is $108 \times 5 = 540$.

The moment of weight is $32 \times B$.

$$\text{Then } 32 \times B = 540$$
$$B = \frac{540}{32}$$
$$= 17 \text{ pounds (nearly).}$$

Had we considered the weight of the valve and lever, we would have added their moments to that of the weight, because these weights increase the weight but not the power.

If in addition to the data given above, the lever weighs 10

pounds and its center of gravity is at its center, that is, 16 inches from the fulcrum. Then

$$\text{Moment of lever} = 10 \times 16 = 160.$$

The valve and valve spindle weigh 8 pounds and are 5 inches from the fulcrum, hence

$$\text{Moment of valve} = 8 \times 5 = 40.$$

$$\text{Total moment of weight} = 32 \times B + 200.$$

The moment of power is, from the previous example, 540, and we have the equation

$$32 \times B + 200 = 540$$
$$32\,B = 540 - 200.$$
$$32\,B = 340$$
$$B = \frac{340}{32} = 10.62 + \text{pounds.}$$

Thus we see that by considering the weight of the valve and spindle and that of the lever, the ball can be reduced in weight from 17 to $10\frac{5}{8}$ pounds.

If the lever is curved as in Fig. 44, the weight arm A becomes the length of the perpendicular from the fulcrum to the line of action of the weight, and the power arm B the length of the perpendicular from the fulcrum to the line of action of the force.

LINK WORK.

Four-Bar Linkage. If we have the four rods AB, BC, CD and DA, Fig. 45, each connected to two of the others by pin and eye joints, each rod becomes what is called a link, and the whole forms a four-bar linkage. If the link AB is fixed in a position (as regards the frame of the machine) the pins at A and B become fixed centers, the links AD and BC become what are called cranks, and the link CD becomes a connecting link or connecting rod. If AD is caused to turn with a uniform angular speed about the pin of A, that is, turning through equal angles in equal periods of time, BC will be compelled to turn with some sort of motion about pin B. Whether BC shall have uniform angular motion and whether it shall make complete revolutions for complete revolutions of AD, will depend upon the relative lengths of the four links.

The center line drawn through the fixed link AB is called the

line of centers, and the center line drawn through the connecting rod CD is called the line of connection. Whatever the relative lengths of the various links, the following law holds true for any position of the linkage.

$$\frac{\text{Angular velocity of crank A D}}{\text{Angular velocity of crank B C}} = \frac{B H}{A K} = \frac{B E}{A E} \qquad (17)$$

That is, if at any given instant the connecting rod be imagined removed and the cranks continue turning at the same speed at which they were moving when the connecting rod was removed, the number of turns of the cranks in a given period of time would be to each other inversely as the lengths of the perpendiculars drawn from the respective fixed centers to the line of connection, and also inversely as the distances from the fixed centers to the point where the line of connection meets the line of centers. A mathematical proof can be given for this law, but it will not be considered here.

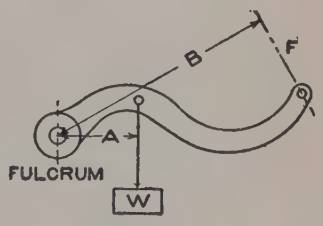


Fig. 44.

If the fixed link AB is made equal in length to the connecting rod DC, and the two cranks are equal (see Fig. 46), the connecting rod will always be parallel to the fixed link, and the perpendiculars BH and AK will always be equal, so that from equation (17) it will be evident that the speeds of the cranks are always equal. An example of a linkage of this kind is found in the parallel rod connecting the drivers of a locomotive, as shown in Fig. 47. The axles of the drivers form the fixed centers A and B, the

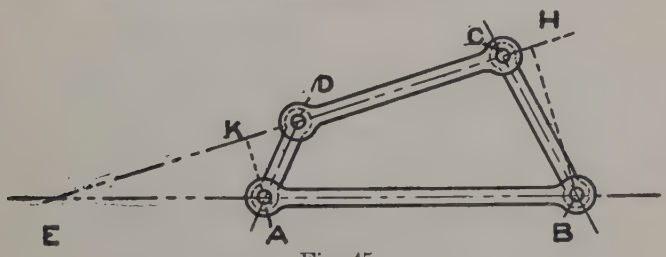


Fig. 45.

frame of the locomotive forms the fixed link AB, the drivers themselves form the cranks AD and BC, and the parallel rod forms the connecting link.

Crank and Connecting Rod. In the four-bar linkage shown in Fig. 45, the pin C is compelled by crank BC to move on the

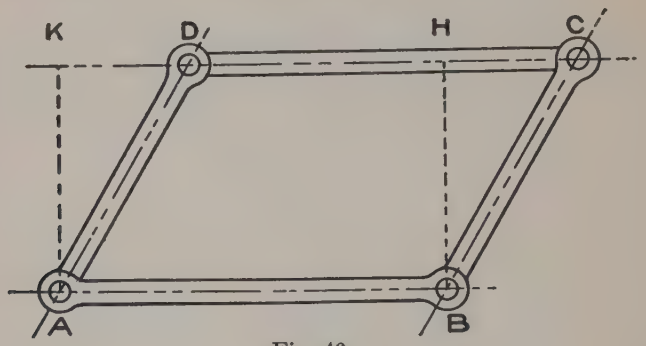


Fig. 46.

arc of a circle whose center is B and radius BC. If in place of BC the fixed link is formed as shown in Fig. 48, being provided with a slot whose radius is BC and center is B, the pin C on the end of the connecting rod will have exactly the same motion that it would if guided by the crank BC. Now, if the radius of the slot

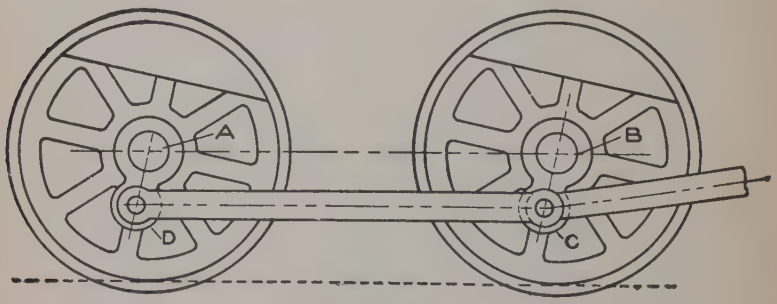


Fig. 47.

is gradually increased, the slot will become nearer and nearer to being straight, so that the linkage shown in Fig. 49, where the slot is straight, may be said to be the limiting case of the linkage shown in Fig. 48. This is the linkage which we have in the crank, connecting rod, crosshead and crosshead guides of a steam engine. The crank shaft corresponds to the pin A, the frame and guides

take the place of the slotted link AC, DC is the connecting rod, and AD the crank.

As there are many problems which may arise in connection with this linkage, particularly as applied to the steam engine, we will consider the most important.

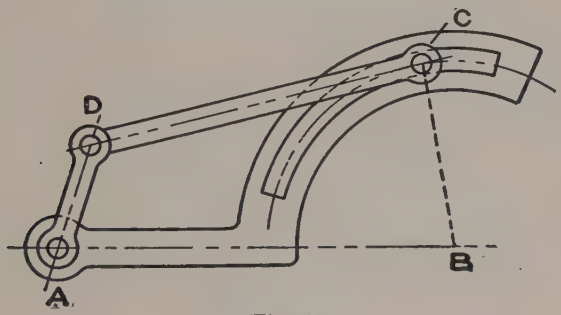


Fig. 48.

Fig. 50 shows the same linkage, the links being represented by their center lines only. AD is the crank, DC the connecting rod, C the crosshead and AC the center line through the crank shaft and the guides.

Suppose the crank has a length R and is making N revolutions per minute at a uniform speed, to find how fast the crosshead is moving at any given position of the crank.

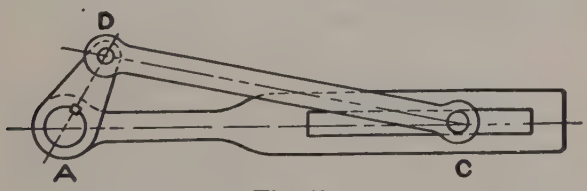


Fig. 49.

We will solve this problem partly graphically and partly by calculation. The first step is to find how fast the crank pin D is moving. For one turn of the crank, D travels through a distance equal to the circumference of a circle whose radius is R, that is, a distance of $2\pi R$. If the crank turns N times per minute the velocity of D must be $2\pi RN$. Knowing the value of R and N, for any particular case we can substite in this formula and find the actual velocity of D. Next draw the linkage at a convenient scale, in the position in which it is desired to find the velocity of C. Draw D*d*

perpendicular to AD and make its length represent at a convenient scale (not necessarily the same scale as was used for the links) the calculated velocity of D. This represents the actual velocity and direction of motion of the end D of the connecting rod at the instant under consideration. Now resolve the velocity D*d* into its components, along and at right angles to DC, by prolonging the

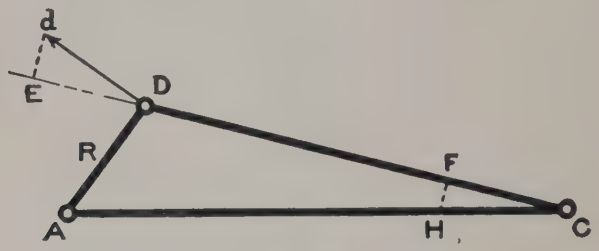


Fig. 50.

line DC and drawing *d*E perpendicular to it. The component DE is the only one which has any effect on the motion of the point C. We have already learned that the motion of the two ends of a rod must have their components along the rod equal, therefore lay off from C, CF = DE. The actual motion of C is along the line CA, and, as CF is one component of the motion, the other component

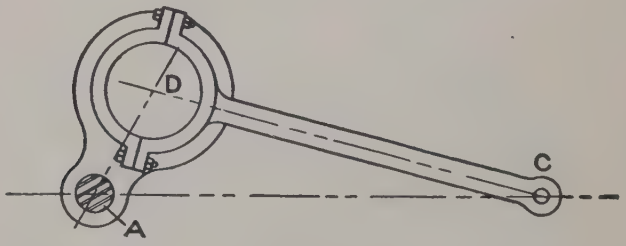


Fig. 51.

must be perpendicular to CF, therefore draw FH perpendicular to CF and meeting CA at H. Then CH is the velocity of point C at the same scale at which D*d* was drawn.

Eccentric. The eccentric and eccentric-rod linkage is in principle the same as the crank and connecting rod. To trace out the connection between the two, let us consider the crank and connecting rod shown in Fig. 51. Here the crank pin D is large and comes almost to the center of the shaft A. By increasing still

further the diameter of the pin D, so that it will take in the shaft, as shown in Fig. 52, we obtain the eccentric.

Considering again the crank and connecting rod linkage: Suppose that in Fig. 53 a force F is applied at the crank pin D in a direction perpendicular to the center line AD; then the pressure which would be exerted by the slide C could be found by the same principle which we have used in previous cases, namely, the forces are inversely proportional to the velocities. Let F be the force at D, and P the pressure at C. Assume any velocity of the point D and represent this at some scale by the line Dd perpendicular to AD. Then find the velocity CH of the point C along the line AC, in the same manner as in Fig. 50. The value of CH can be measured off at the same scale at which Dd was drawn. Then

$$\frac{F}{P} = \frac{CH}{D\,d} \qquad (18)$$

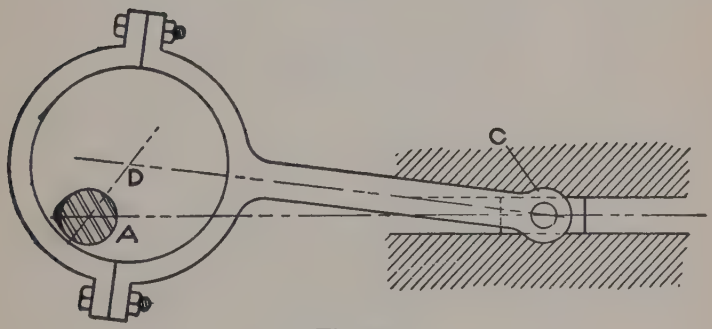


Fig. 52.

from which, if one of the quantities F or P is known, the other may be found.

If the value of CH is found for various positions of AD, keeping Dd constant, it will be seen that the nearer AD comes to coinciding with AC, the smaller CH becomes, and from equation (18) it will appear that the smaller CH is, the greater P becomes with relation to F. The above discussion will hold true if the force acts in the direction Dd or in the opposite direction.

The linkage used in this way to effect pressure at c by a force on D is known as the *toggle joint*, and is used with more or less modification in several kinds of machinery, such as punching machines, brakes on the drivers of a locomotive, etc. The force need

not be applied at D, but may be applied at some other point on AD, or on some piece rigidly connected to AD but making an angle with it. This is shown in Fig. 54. Here the force is applied at E, and we can find the force at C by the same principle as before: The force at C is to force at E inversely as the velocities of C and E. The only difference is in finding the velocity of C. Assume a velocity for E, as E*e*. Then

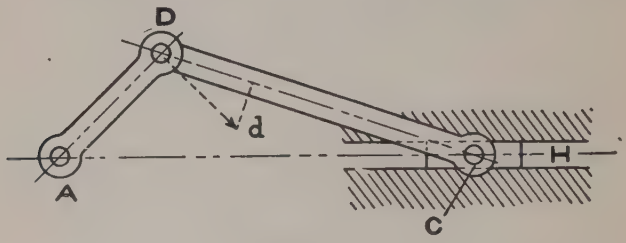


Fig. 53.

$$\frac{\text{Velocity E}}{\text{Velocity D}} = \frac{\text{A E}}{\text{A D}} \qquad (19)$$

from which the velocity of D may be found; the rest of the solution would be the same as for Fig. 53.

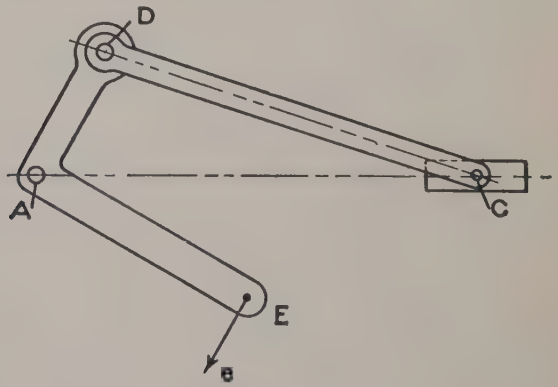


Fig. 54.

These problems may be solved by another and perhaps somewhat shorter method, but, as this would involve the resolution of forces, which have not yet been taken up in detail, we will confine ourselves to the above method.

QUICK RETURN MOTIONS.

In various kinds of machinery, particularly machine tools, it is desired to move a piece backward and forward; the forward motion being slow and the return motion more rapid. Take for example the shaper; as the tool when moving forward is cutting metal, it should go slowly and steadily, but after the cut is made it is desirable to get the tool back ready for its next stroke as quickly as possible. Many different devices are used to accomplish this result.

If in Fig. 45 we replace the connecting rod DC by a slot in the link BC, we get the linkage shown in Fig. 55. A and B are the fixed centers, AD is the driving crank (which usually turns

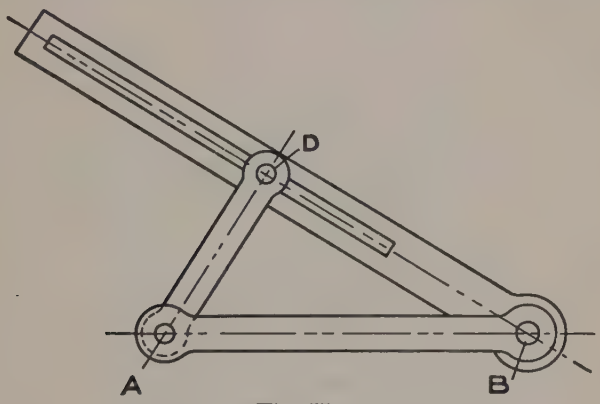


Fig. 55.

with uniform speed), BD is the slotted crank and to some part of BD a link or some other piece is connected by means of which the tool is driven. Two distinct mechanisms are formed, depending upon the relative lengths of the links. If the proportions are such that a circle drawn around the center A, with radius AD, falls outside the center B, as shown in Fig. 56, we have what is known as a Whitworth quick return motion. Here the slotted crank makes one complete revolution for each complete revolution of AD, but its speed is not uniform. In this figure, a connecting rod PT is represented as attached to a point P on the slotted link. The other end of this connecting rod moves the tool holder T along the straight line BT. When the linkage is in the position shown, T is in its extreme right-hand position, and it will be in its

extreme left-hand position when BP occupies the position BP_1. In turning BP through this angle (180°), AD has turned through the angle L. In returning BP to its right-hand position again, AD has to turn through the angle M only. Now, since AD turns with uniform speed and since angle M is less than angle L, T makes its stroke from left to right in less time than was required to move from right to left. The time of advance and time of return are in the ratio of angles L and M. If the length of the crank AD and the ratio of time of advance to return are known the distance AB may be found as follows:

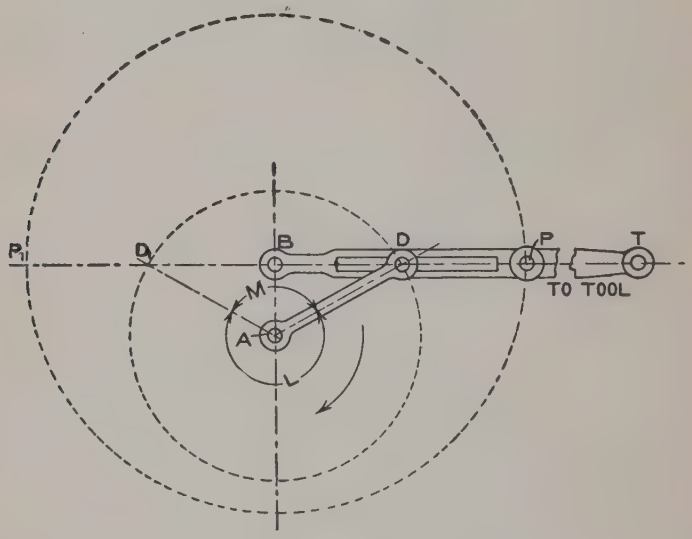


Fig. 56.

With A as a center and AD as a radius, draw a circle and divide the circumference by the points D and D_1 so that angle L may bear the same ratio to angle M that the time of advance bears to the time of return. Join D and D_1 and from A draw a line perpendicular to DD_1, meeting it at B, which will be the required center for the driven crank.

The distance BP governs the length of the stroke of the tool, so that by varying the position of P the length of the stroke may be varied.

If the proportions of the linkage are such that a circle drawn with A as a center and a radius AD comes inside the point B,

that is, if AD is less than AB,we have what is known as a swinging block linkage. Fig. 57 shows this form of quick return motion. The piece which drives the tool is attached to the slotted link at P, which may be anywhere along the link. The linkage is shown at the extreme right of its stroke, the point D being at the point where the center line of the slot is tangent to the circle drawn with center A and radius AD, (that is, the length of the driving crank). AD_1 is the corresponding position of the crank

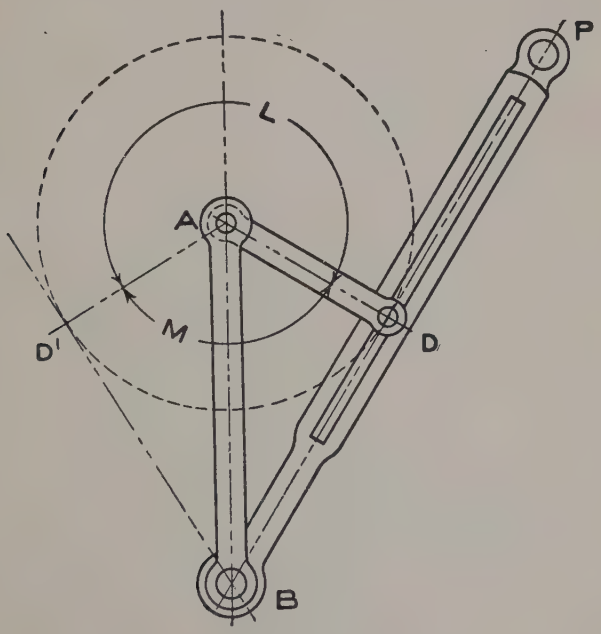


Fig. 57.

at the other extreme of the stroke. The time of advance is to the time of return as angle L is to angle M, as in the case of the Whitworth quick return. If the ratio of advance to return and the length of AD are known, the position of B may be found by drawing the circle with center A and radius AD, and on this circle finding points D and D_1 such that the angles L and M shall have the required ratio. Then draw DB and D_1B tangent to the circle at D and D_1 respectively, meeting each other at B, which is the required center for the driven crank.

GEARING.

If shaft B, Fig. 58, has fastened to it a disc with smooth circumference, the disc being in contact at the point P with another disc on shaft A, the rotation of one shaft will cause the other to rotate, provided there is sufficient friction between the two surfaces to prevent slipping. According to the principles which we have already learned, the following equation will hold true:

$$\frac{\text{Revolutions per minute of A}}{\text{Revolutions per minute of B}} = \frac{\text{B P}}{\text{A P}}$$

In practice, the friction would not be sufficient to be relied upon, so that discs having teeth upon their circumference are used, instead of the plain discs. The discs or wheels thus formed are called gears. The teeth may have any one of several forms, and the gears may connect shafts which are parallel, intersecting at some angle, or neither parallel nor intersecting. Two gears such as shown in Fig. 59, where the shafts are parallel and the teeth on the circumference are parallel to the axis of the gear, are called **spur gears.**

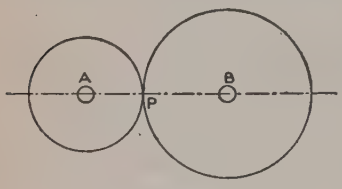


Fig. 58.

The two dot and dash circles drawn about the centers A and B and in contact at P correspond to the two discs of Fig. 58, and the gears may be said to be derived from these circles, which are called the **pitch circles.** The diameters of these circles are called the **pitch diameters** of the gears. The point P, where the two pitch circles touch each other, is called the *pitch point.* Circles drawn through the outer ends of the teeth are called the *addendum cirles,* and circles drawn at the bottom of the teeth are called the *root circles.* These circles are indicated on the figure. That part of the tooth outlined between the pitch circle and the addendum circle, as PE, is called the **face** of the tooth, and that part between the pitch circle and the root circle, as PF, is called the **flank.** The radius of the addendum circle minus the radius of the pitch circle is called the addendum distance, or simply the *addendum.* The radius of the pitch circle minus the radius of the root circle is called the *root distance* or the *root.* The root is commonly

made a little greater than the addendum, so that when two gears have their pitch circles in contact, if their teeth are of equal length they will not touch bottom, but will have some clearance. The distance from the center of one tooth to the center of the next, measured on the pitch circle, as GH, is called the **circular pitch,** or **circumferential pitch,** and is equal to the circumference of the pitch circle divided by the number of teeth.

In order to run together, two gears must have the same circular pitch. The number of teeth on two gears of the same pitch are proportional to the circumferences, and, consequently, to the diameters of their pitch circles; and as the speeds of the two shafts

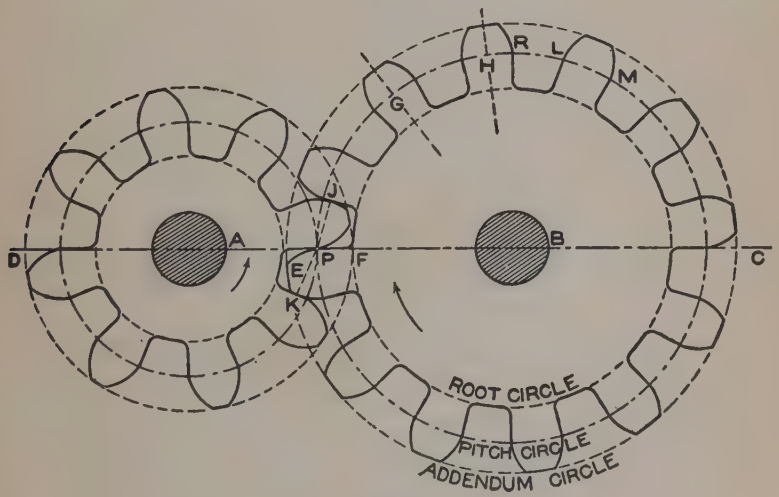
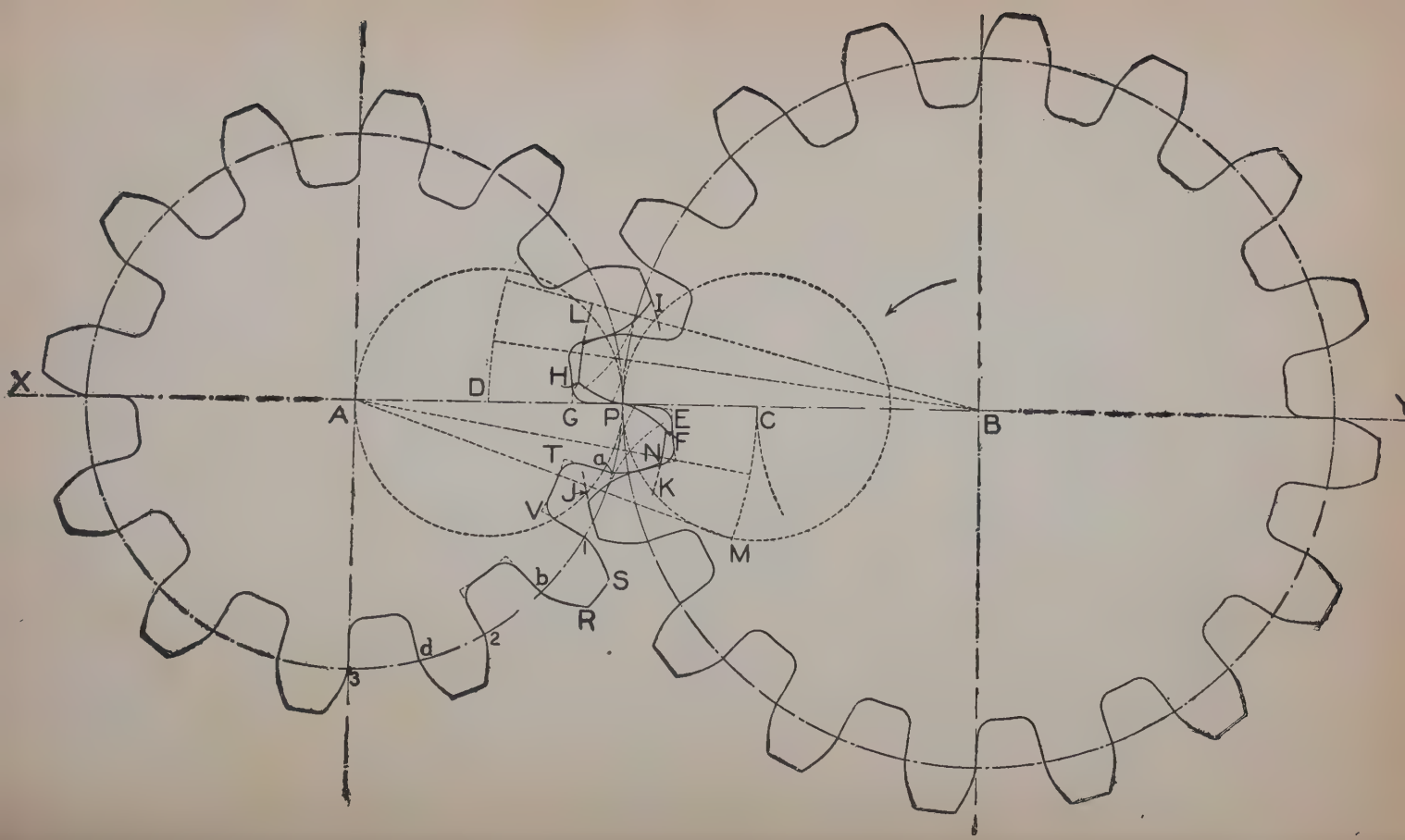


Fig. 59.

which are connected by a pair of gears are inversely proportional to the diameters of the pitch circles of the gears, the speeds must also be inversely proportional to the number of teeth.

On rough gears the width of the tooth LM is made a little less than the width of the space RL, to allow for irregularity of construction. The difference in the width of the two is called the *back lash.*

Although the circular pitch is a term which is frequently used in connection with gearing, there is another kind of pitch which is often used. This is the **diametral pitch,** and is equal to the diameter of the pitch circle divided by the number of teeth, or, in other words, the amount of pitch diameter allowed for each


X
Y
A
B
C
D
E
F
G
H
I
L
M
N
P
R
S
T
V
a
b
d
1
2
3

tooth. The diametral pitch bears the same relation to the circular pitch that the diameter of a circle bears to its circumference; that is, the diametral pitch is equal to the circular pitch divided by π. In speaking of the pitch of a gear, instead of using the diametral pitch, which is often a fraction, it is customary to use only the denominator of the fraction. For example, if the diametral pitch is $\frac{1}{2}$ inch, it would be spoken of as a 2-pitch gear. This would be the same as saying that for every inch of pitch diameter there are two teeth.

Problems similar to the following often arise in this connection:

1. Given two gears, 4 pitch, having 12 teeth and 16 teeth respectively, to find their pitch diameters and the distance apart that their centers should be located, to run properly.

Since they are 4 pitch, their diametral pitch is $\frac{1}{4}$ inch and their pitch diameters will be their numbers of teeth multiplied by $\frac{1}{4}$, so that one would be $12 \times \frac{1}{4} = 3$ inches in diameter, and the other $16 \times \frac{1}{4} = 4$ inches in diameter. The distance on centers will be the sum of their pitch radii $= \frac{3}{2} + \frac{4}{2} = 3\frac{1}{2}$ inches.

2. Given two gears, 8 pitch, having diameters 6 and 10 inches respectively, to find the number of teeth.

The expression "8 pitch," besides meaning that the diametral pitch is $\frac{1}{8}$ inch, means that there are 8 teeth for every inch of diameter, so that one gear will have

$$8 \times 6 = 48 \text{ teeth}$$

and the other $8 \times 10 = 80$ teeth.

Referring again to Fig. 59: If gear A is driving the other gear in the direction indicated, there is a working point of contact between the teeth of the two gears at J and another at K, and as the gears turn and the teeth slide along each other, the point where a pair of teeth is in contact changes. If from the point of contact, as J, a line is drawn to the pitch P, the tooth curves should have such form that this line is normal to both curves at J; that is, PJ should be perpendicular to a line drawn tangent to both curves at J. This condition should hold, wherever the point of contact may be, in order that the gears may run smoothly.

There are two kinds of curves which are commonly used for the outlines of gear teeth, and which fulfill the above conditions.

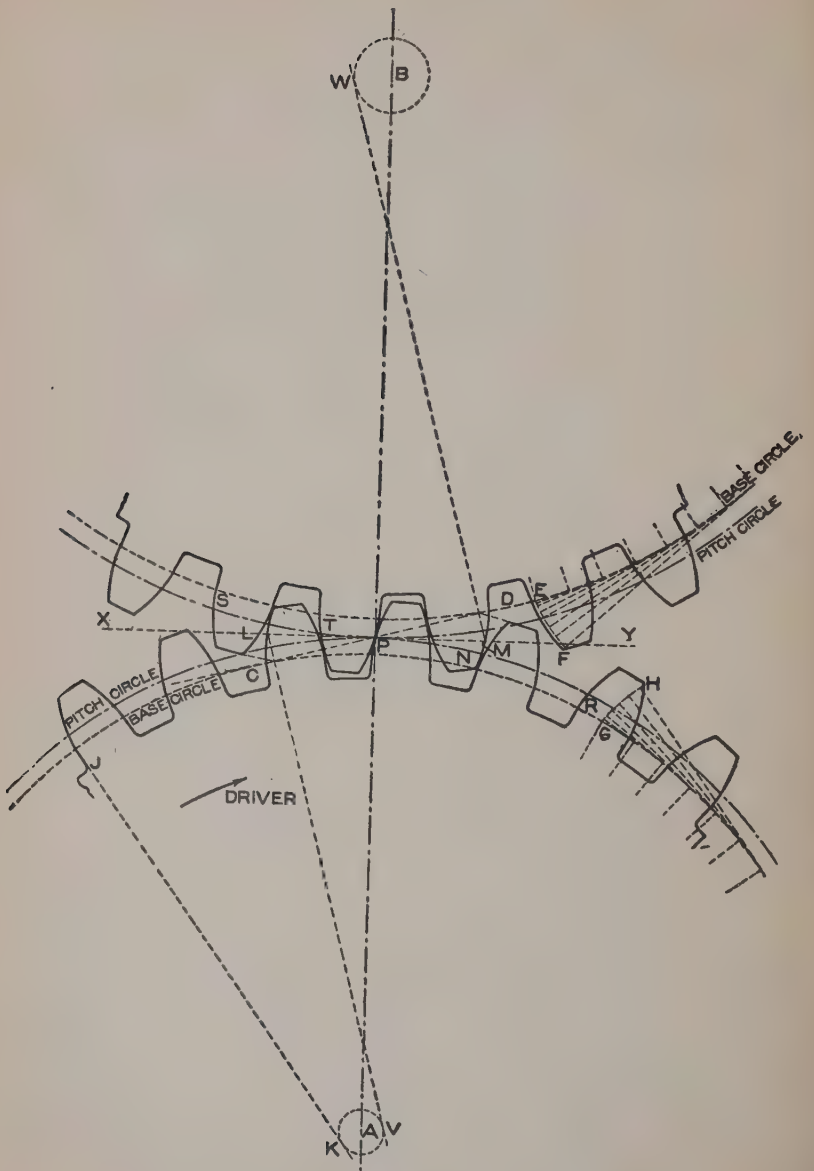

W
B
BASE CIRCLE
PITCH CIRCLE
X
S
L
T
D
E
Y
N
M
F
H
R
G
PITCH CIRCLE
BASE CIRCLE
C
J
DRIVER
K
A
V

Fig. 61.

These are the **involute** and the **epicycloidal** curves. Fig. 60 shows a pair of gears with epicycloidal teeth and Fig. 61 shows parts of two gears with involute teeth. The construction for getting the tooth outlines is shown in the figures, but as this properly comes under the subject of drawing, and is not essential to an understanding of gears in general, it will not be explained here.

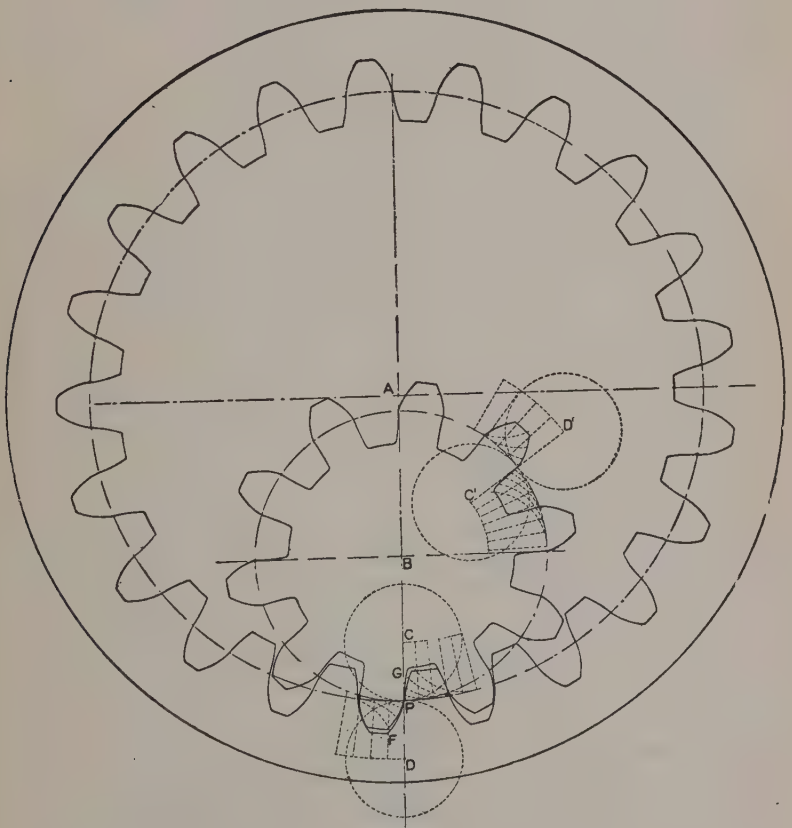


Fig. 62.

Annular Gears. An annular gear is a ring with teeth on its inside edge. Fig. 62 shows such a gear with center at A, meshing with a small spur gear called the pinion.

Rack and Pinion. A rack is a gear whose pitch line is a straight line instead of a circle. Fig. 63 shows an epicycloidal rack in gear with a pinion.

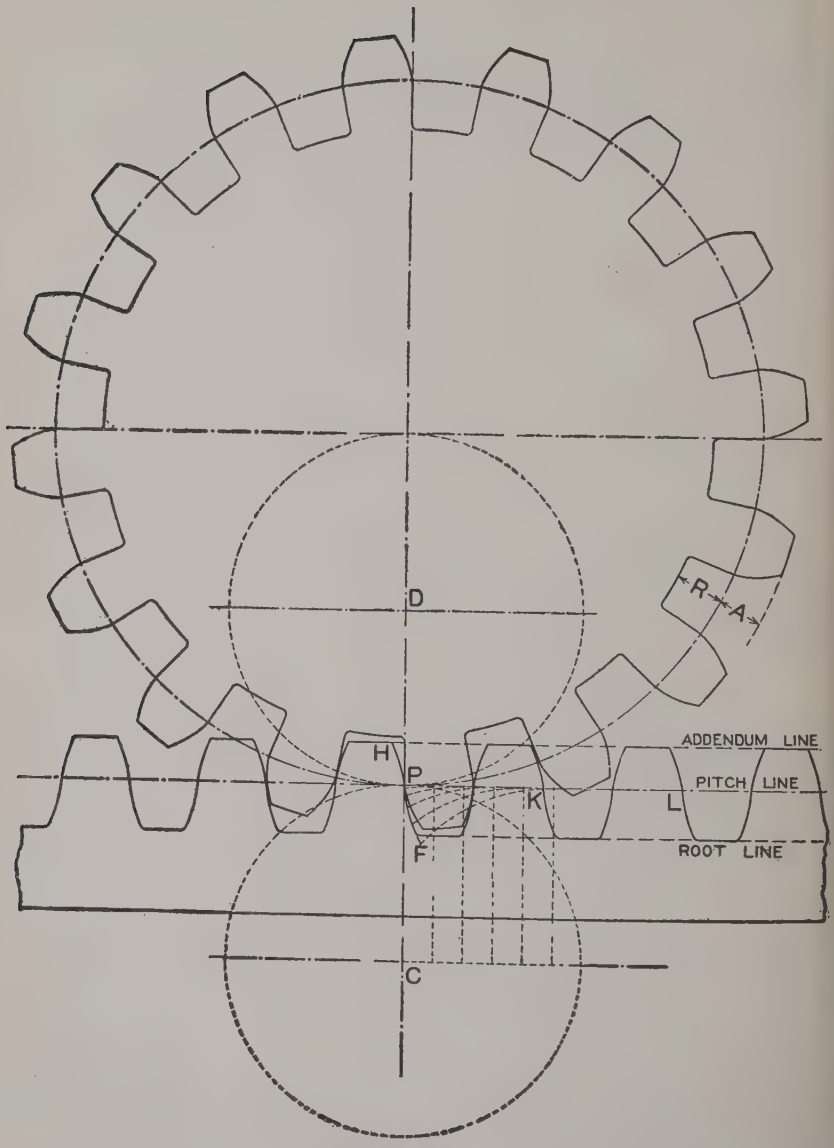


Fig. 63.

Bevel Gears. When two shafts whose axes intersect are to be connected by gears, the gears commonly used are called bevel gears. The theoretically correct pitch surface of a bevel gear is a part of the sector of a sphere, but as the designing and making of such a gear is somewhat difficult, a cone is substituted for a sphere. Fig. 64 shows a pair of bevel gears connecting two shafts

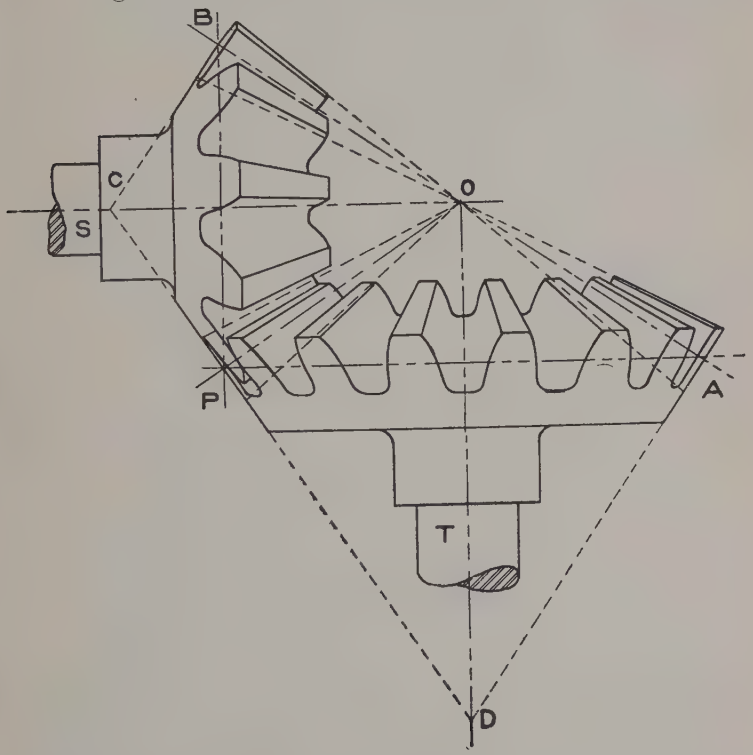


Fig. 64.

which are at right angles. O is the point where the center lines of the shaft intersect, OPA and OPB are the *pitch cones* of the gears, AP and BP the pitch diameters.

The speed of the shaft S is to the speed of the shaft T as AP is to BP. The teeth may be epicycloidal or involute, and the shafts may be at right angles or at some other angle.

Trains of Wheels. Thus far both in gearing and in pulleys and belts, we have considered only one pair of wheels, one being on the driving shaft and the other on the driven shaft. It very

often happens that the connection cannot be made directly by one pair of wheels, either because the shafts are not conveniently placed with relation to each other, or because the diameters cannot be so proportioned as to give the desired speed. In such cases the connection may be made by a train of pulleys or a train of gears. Fig. 65 shows a train of pulleys, and Fig. 66 a train of gears.

In Fig. 65 shaft A drives shaft B by means of pulleys E and F. B in turn drives C by means of pulleys G and H, and C drives D by pulleys J and K.

Assume shaft A to make 100 R. P. M. and the pulleys of the following diameters:

E = 36 inches	G = 24 inches	J = 20 inches
F = 12 inches	H = 18 inches	K = 10 inches,

to find the number of revolutions of shaft D. Applying the principles which we have already learned,

$$\frac{\text{R. P. M. of B}}{\text{R. P. M. of A}} = \frac{\text{Diameter of E}}{\text{Diameter of F}} \quad \text{or}$$

$$\text{R. P. M. of B} = \text{R. P. M. of A} \times \frac{\text{diam. of E}}{\text{diam. of F}} = 100 \times \tfrac{36}{12}$$

$$\text{In like manner R. P. M. of C} = \text{R. P. M. of B} \times \tfrac{24}{18}$$
$$= 100 \times \tfrac{36}{12} \times \tfrac{24}{18},$$

$$\text{and R. P. M. of D} = \text{R. P. M. of C} \times \tfrac{20}{10}$$
$$= 100 \times \tfrac{36}{12} \times \tfrac{24}{18} \times \tfrac{20}{10}$$
$$= 800.$$

It will be noticed that pulleys E, G and J are drivers and F, H and K are driven pulleys, so that the above may be stated thus:

Revolutions of last shaft (or last wheel) = revolutions of first shaft (or first wheel) multiplied by a fraction whose numerator is the product of the diameter of all the *driving* pulleys, and whose denominator is the product of the diameters of all the *driven* pulleys. **(20)**

The same rule will apply to the train of gears in Fig. 66, if we use either the pitch diameters or the number of teeth in the respective gears where diameters are used instead of the pulley diameters.

In Fig. 65, where all the belts are open belts, all the shafts

turn in the same direction; but where two shafts are connected by a pair of spur gears, the shafts turn in opposite directions, so that, in Fig. 66, the direction in which shaft D will turn with reference to the direction of A, will depend upon the number of gears in the train. The best way to determine this is to follow the train through, putting arrows, as shown, on the respective shafts.

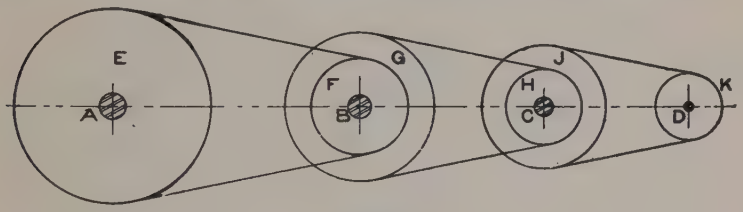


Fig. 65.

Idle Gear. In Fig. 67, gear E drives gear F, and F drives G, that is, F is both a driven and driving gear. Let E have 25 teeth, F 30 teeth, and G 50 teeth, and let shaft C make 100 R. P. M. Then from the rule given above,

$$\text{R. P. M. of A} = 100 \times \tfrac{25}{30} \times \tfrac{30}{50}.$$

In this equation the number of teeth of F (30) occurs both in

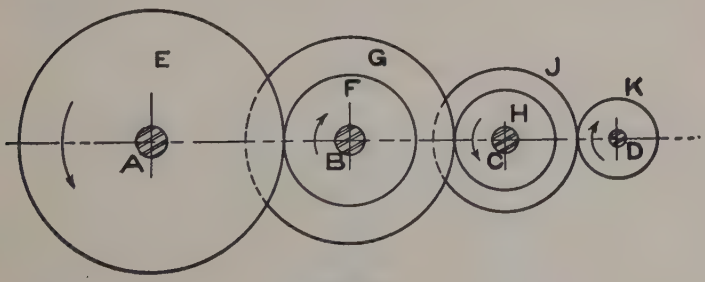


Fig. 66.

the numerator and denominator of the fraction, and will therefore cancel each other, so that the equation becomes

$$\text{R. P. M. of A} = 100 \times \tfrac{25}{50}.$$

Therefore, the speed of A depends only upon the number of teeth in E and G. Gear F is called an idle gear or idler. It should be noticed, however, that A will turn in the opposite direction from what it would if G geared directly with E.

In any train of wheels, the number of turns of the last wheel

(as K in Figs. 65 and 66, or G in Fig. 67) divided by the number of turns of the first wheel, as E, is called VALUE OF THE TRAIN. Considering this statement in connection with formula (20) we have the following:—

$$\text{Value of train} = \frac{\text{Product of teeth of all drivers}}{\text{Product of teeth of all driven wheels.}} \qquad (21)$$

This value will be positive or negative, that is, it will have the algebraic sign + or — before it, according as the last wheel turns in the same direction as the first, or in the opposite direction.

Epicyclic Trains. In Fig. 68 the gear B is loose on the shaft H and driven by the gear E; arm A is keyed to the shaft H so that it turns when the shaft turns. Gears C and D are carried on studs on the arm. It will be evident that if B and H are caused

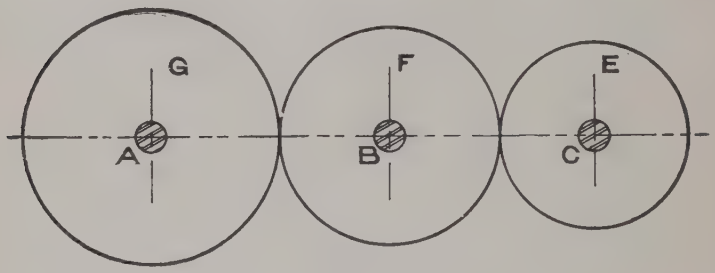


Fig. 67.

to turn independently, the gear D will have a different number of turns on its own axis from what it would if A were fixed and D were driven directly through the train BCD.

In the following formula, the value of the train is the ratio of the turns of D to the turns of B if the arm were fixed, considering B the first wheel and D the last; by the turns of B and D respectively we mean the actual number of turns they make when the arm is in motion. The formula by which the turns of A, B, or D can be found is as follows,—

$$\text{Value of train} = \frac{\text{Turns of last wheel} - \text{turns of arm}}{\text{Turns of first wheel} - \text{turns of arm}} \qquad (22)$$

This can be easily proved, but the proof need not be studied to understand the use of the formula. In applying this, the proper algebraic signs must be given to the value of the train. and the

turns of the arm: That is, if with the arm fixed, B and D would turn in the same direction, the value of the train is considered plus, if in opposite directions, the value of the train is minus. If the arm turns in the same direction as B, the turns of the arm would be plus, but if in the opposite direction the turns of the arm would be minus, so that the formula would become,

$$\text{Value of train} = \frac{\text{Turns of last wheel} + \text{turns of arm}}{\text{Turns of first wheel} + \text{turns of arm}}$$

That is, two minus signs before the number of turns of arm would make it plus. This may be more clearly understood from a study of the following problems:

In Fig. 68 let B have 75 teeth, C 30 teeth and D 25 teeth, and let B be driven by E at a speed of 20 R. P. M. right-handed,

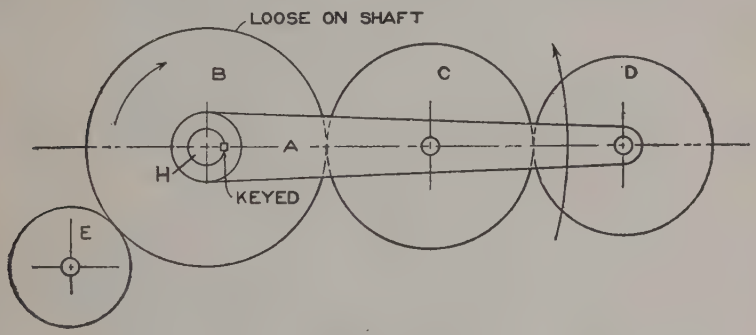


Fig. 68.

while A is driven at a speed of 2 R. P. M left-handed, to find the number of R. P. M. of D and the direction in which it will turn. We will use formula (22). The value of the train will be found from formula (21).

$$\text{Value of train} = \frac{\text{Teeth of B} \times \text{Teeth of C}}{\text{Teeth of C} \times \text{Teeth of D}}$$

$$\text{Value of train} = \tfrac{75}{30} \times \tfrac{30}{25} = 3$$

and since with the arm fixed B and D would turn in the same direction, the value of the train will be plus. Since the arm A turns in the opposite direction from B, its number of turns will have a minus sign. Then substituting the formula (22.)

$$3 = \frac{\text{R. P. M. of D} - (-2)}{20 - (-2)} = \frac{\text{R. P. M. of D} + 2}{20 + 2}$$

or

$$3 \times 22 = \text{R. P. M. of D} + 2$$

whence

$$64 = \text{R. P. M. of D}$$

In Fig. 69 the gear B, the arm A, and the annular gear D have a common axis, but are arranged to turn independently of each other about this axis. C is an idle wheel connecting B with the annular gear D and is on an axis carried by A. Let B have 30 teeth, C 45 teeth and D 120 teeth, and let B be caused to have 125 R. P. M. right-handed and arm A have 75 R. P. M. left-handed, to find the number of turns and direction of motion of D. First find the value of the train if A were fixed, which would be

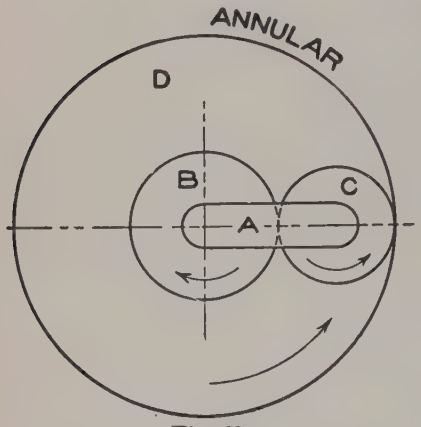


Fig. 69.

$$\frac{(30 \times 45)}{(45 \times 120)} = \frac{1}{4}$$

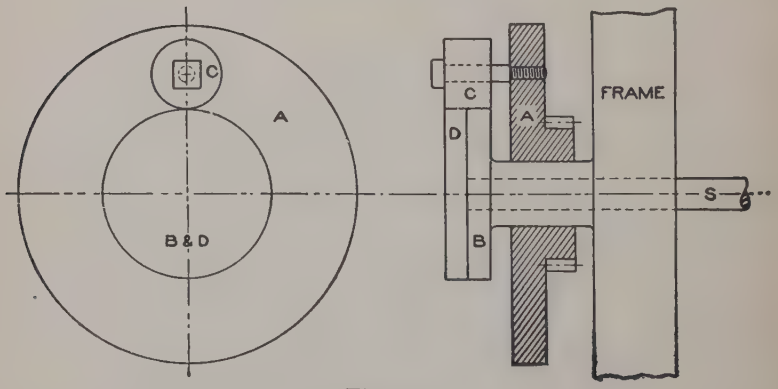


Fig. 70.

thence substituting in formula (22).

$$-\frac{1}{4} = \frac{\text{Turns of D} - (-75)}{125 - (-75)} = \frac{\text{Turns of D} + 75}{200}$$

whence turns of D $= -125$

that is D, makes 125 R. P. M. in the opposite direction from that in which B is turning.

In Fig. 70, gears B and D have a common axis, B is fast to the frame of a machine, D is fast to the shaft S, which drives the work on the machine, A is a disc centered on the hub which supports B, and driven by a gear (not shown) which meshes with a gear on the back of A. C is a gear carried on the stud in A. The gear B corresponds to the first wheel or driver of an epicyclic train, A to the arm, C is an idle wheel, and D is the last wheel of the train. B has one tooth more than D. Let B have 35 teeth, C 15 teeth, D 34 teeth, and let A make one turn right-handed, to find the speed of D and the direction of its motion. The value of the train, considering A fixed and B the driver, is $\frac{35}{34}$. Then formula (22).

$$\frac{35}{34} = \frac{\text{Turns of D} - 1}{0 - 1}$$

$$\text{or } -35 = 34 \text{ Turns of D} - 34$$

$$-1 = 34 \text{ Turns of D}$$

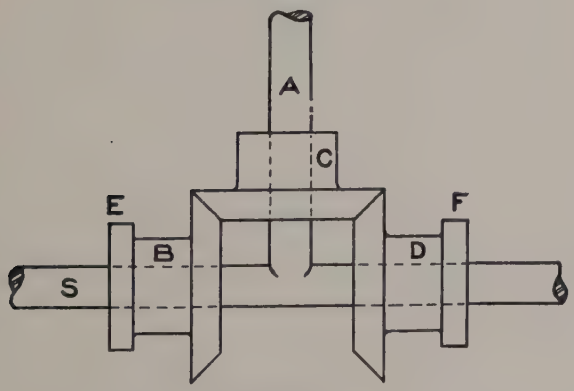


Fig. 71.

or Turns of D $= -\frac{1}{34}$. That is, for one turn of A right-handed, with B fixed, D makes $\frac{1}{34}$ of a turn left-handed.

In Fig. 71 is shown an epicyclic train of bevel gears. The shaft S carries the shaft A either welded to it or clamped on it in some way. Loose on S are the bevel gears B and D, held in place by collars (not shown) and loose on A is the bevel C, gearing with each of the others. Fast to B is the spur gear E, which is driven from some source of power not shown. S is driven from

some external source of power, thus causing the arm A to swing around. Let all of the bevels have the same number of teeth, and let B be driven at a speed of 50 R. P. M. right-handed, and S at a speed of 25 R. P. M. right-handed, to find the speed and direction of D. Formula (22) applies here as in other cases which we have considered.

$$\text{The value of the train} = -1$$

$$\text{Then } -1 = \frac{\text{Turns of D} - 25}{50 - 25}$$

$$-25 = \text{Turns of D} - 25.$$

$$\text{Therefore, Turns of D} = 0.$$

Again let B turn 50 R. P. M. right-handed, to find the direction and number of turns of A in order that D shall turn 25 R. P. M. left-handed.

$$-1 = \frac{-25 - \text{Turns of A}}{50 - \text{Turns of A}}$$

$$-50 + \text{Turns of A} = -25 - \text{Turns of A.}$$

$$\text{Therefore, Turns of A} = 12\tfrac{1}{2} \text{ right-handed.}$$

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